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MATRICULATION BOTANY

MATRICULATION BOTANY

A NEW SCHOOL COURSE

BY

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B.Sc., F.L.S.

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PREFACE

This book has been designed to meet the needs of students preparing for examinations of Matriculation standard. The range of study adopted in such preparation is taken as being liberal, going beyond the bare requirements of the examination syllabus. Certain chapters lay the foundation for Higher Certificate work.

The arrangement of the subject-matter is governed by two fundamental ideas. First, to a large extent general knowledge of plant life is considered to be best acquired through the detailed study of the life-histories of a few specially selected plants; this entails first-hand continued observation of the living plant. Second, ecology, the investigation of plants in relation to their environment, is not reserved for late and detached consideration; it is treated as an integral part of plant study from the beginning. It may be difficult to realise these aims in some schools; but the necessary effort will be well repaid. For the town school, the difficulties of outdoor work are undoubtedly great, but the town child's need for it is also great. Every chance of a day with nature must be taken advantage of, the communal spirit which prompts the more favourably placed child to bring in specimens and records of observations for its class-mates should be fostered, whilst one well-planned week spent in a country camp will accomplish wonders in stimulation and in demonstration of right methods of approach to botanical study.

Some introduction to the many interests which are associated with pure botany is offered; the medicinal history of plants, their names, the mysterious bonds connecting plant and animal, the national importance of agricultural research, the diversity of quests upon which the student may embark in his future studies.

There is no point in tempting pupils to depend on the efforts of others rather than on their own, hence it has been thought undesirable as well as unnecessary to multiply illustrations. In one school in which the scheme of life-histories is adopted, the pupils work for two years without a botanical textbook of any kind. By the end of that time each has compiled and illustrated a simple book of her own.

With three exceptions, for which due acknowledgment is made, the illustrations in this book are new. For many of them I am indebted to the sketch-books of girls in our school; I make my acknowledgments to them with gratitude: to Joan Francke for figures 1, 4, 8, 21, 24, 34 (part), 38, 44, 47, 49, 51, 52, 69, 80 (1), 82, 87, 92, 118; to Olga Haigh for 25, 30, 78, 79, 107 (1), 117; to Audrey Bradbury for 23, 33, 77, 80 (2) (3), 83, 110 (3); to Elsie Allen for 53, 85, 88; to Ellen Towler for 43, 106; and to Stella Hausman for 81. The final preparation of most of the drawings for publication has been done by Constance Clegg, a former art student of the school.

I am under extremely great obligation to Miss Vera Greenwood. Her suggestions regarding the scope of the book have been acted upon repeatedly; she read the manuscript as each chapter was finished, and her criticisms I found most valuable. I am deeply grateful to her.

I should like also to thank those who, throughout the passage of the book through the press, have so courteously and with such extreme care advised and corrected me, and set forth the matter of this book in correct and seemly form.

M. A. J.

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A WORD TO THE STUDENT

I HOPE that the word will be read and acted upon.

Real botanical knowledge—a genuine knowledge of the plant as it lives—this book will not give you, cannot give you. That will be yielded up to you only by the plant itself, and to the plant you must go for it. You must be prepared to toil for it; they will talk to you of themselves, those roots and branches and leaves, but only after persuasion. The book will try to give you guidance in your quest; it will place before you some of the facts that other students have brought to light after lifetimes of patient endeavour. The book may fail in interest; the plants never will: they are too cunningly constructed, too provoking in their mysteries, too full of charm. The recognition of problems and the tracking down of the solutions of them: that is one way of looking at the study of botanical science.

Look everywhere for problems. Keep your eyes open for the quick changes which pass over vegetation—in the garden, in the hedgerow, in the city park, in the trees that hang over the suburban road; can you find other changes which may account for them? One morning you find in the garden that Dahlia and Nasturtium have become limp, sodden and blackened; they have had the first touch of frost. A morning of hard frost in mid-winter shows the leaves of Rhododendron drooping in tent-like circles. You may notice, too, that Rhododendron, brought young into the fume-laden air of a city park, flowers for one season, but never again. One day you are surprised by the bursting of hawthorn buds; on successive days, on your morning journey, you may watch the changing curvatures of graceful birch-boughs, weighted by gradually swelling buds.

Do not place a bottomless gulf between plant and animal. They are formed fundamentally of one living matter. So real is their relationship that theory says they are descended from a common ancestor. Look for points of correspondence between them.

At the very beginning of your work prepare a set of notebooks in which to record observations, experimental work, etc. Classify your entries for easy reference and index them. Date them; an entry may be rendered of little value by the absence of this particular. Set out with the idea that they are going to be of permanent value for future consultation; therefore, they must be accurate, methodical and complete as far as can be. Orderly notebooks indicate orderly minds, and help to make minds orderly.

Directions given in this book for experiments suggested may not always be as thought-saving as you would like; you must think them out for yourself. Keep many little experiments of your own on the way, even if your private facilities do not get beyond flower-pots.

You will probably find fewer illustrative sketches here than you like; you must make your own. At the end of your school course you should possess books full of them, and every one should be correct enough to refresh your memory years after. Botanical drawings require a distinctive style. Your aim is not to produce a pretty picture, but a clear and true one: it must be exact in every line and dot selected, but it need not include every line and dot. It may be diagrammatic. Let there be no vague attempts at shading; at most, use a few lines graduated to give definition to form. Aim at light, clear lining, careful junctions of lines, correct proportions. Make careful choice of the details required to bring out the chief points you wish to record. Pay due regard to perspective in drawing apparatus. Adopt a neat system of labelling and setting out descriptive matter. Indicate the scale of the drawing, and do not forget to put in the date.

Make a point of acquiring technical terms directly they are needed; use them; they will soon come to you readily. On page 312 is a short list of Greek roots which enter largely into the composition of botanical terms. If you memorise these they will help you towards an intelligent grasp of new words.

In conclusion, keep your mind fresh. There are real marvels in the world of plants; we realise them if we do not let our minds get deadened with words. What conjurer can bring coal out of the clear air? The plant has done it.

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MATRICULATION BOTANY

CHAPTER I

THE PLANT IN OUTLINE

Again it may be said that it is the living plant that you must know, and that as often as possible you must see it in the places where it lives in nature. Let that be your aim in all your botanical work. A helpful introduction to more systematic examination of plants will be to take a rapid glance at some of their outstanding characters, just as a comprehensive view of a district obtained from a hill-top is a useful preliminary to the detailed survey of it.

Indulge in at least one country ramble with no better defined purpose in your mind than to keep your eyes open for anything and everything in the world of plants. Pull down the branches and look for their secrets; pull up the weeds and ask what they are hiding in the earth. Take the wild-flower and break it apart; look curiously at the fruits which are ripening and at the fruits which are lying about or are floating in the wind. See the determination with which the tree-top and the grass-blade alike strike upwards. I wonder if at the end of the day you say to yourself, " Why should every plant thrust one extremity of its axis straight up into air and light, and the opposite straight down into soil and darkness? " A mite of a child may see that it is so; can anyone really tell us why? You may at first think this too simple to be science; you have, in truth, met on the threshold of your scientific journey one of the hardest problems of the science.

To get a general idea of the build of plants, a Wallflower in its second year of growth is probably as suitable as any; Foxglove will serve, so will Snapdragon, and you may find various others.

Suppose you choose the Wallflower. Remove a well-grown plant from its bed most carefully. Try to free the roots from soil by shaking and by rinsing under the tap; you will find that fine particles of soil cling persistently to the most delicate of the roots; remember this for future inquiry.

(*a*) UNDERGROUND STRUCTURES

The centrally placed, main axis underground grows as a straight-line continuation of the axis which appears above ground. It is the primary root. When Wallflower seedlings are in season you must note in them the earlier appearance of this now substantial root. From the main root there arise roots of second rank, the *laterals* or *secondary roots*; their direction of growth lies somewhere between horizontal and vertical. The laterals branch and re-branch, the final rootlets being very fine indeed: it is these last which retain a coating of soil extending nearly, but not quite, to their tips. When within the soil, each root-tip would bore out its own little burrow, keeping well clear of its neighbours, and forming part of a beautiful system of social economy, as you will see later. A fairly young plant shows that the secondary roots break out of the main root in an ordered manner; generally there are four longitudinal rows of them; an explanation of this, which depends on the arrangement of microscopic elements in the parent root, comes in Chapter XVI. The largest and oldest roots are at the higher levels; the last formed are at the lowest—that is to say, the growing region of the root must be at or near the tip. In old plants, particularly after they have been transplanted, the root system becomes less regular, less easy to follow; therefore use young plants for these observations.

(*b*) AERIAL STRUCTURES

Transfer your attention now from the root to the *shoot*, that portion of the main axis which grows up into the air. Tapering upwards, it passes from a hard, woody structure, covered with a thin brown bark, to one which is green and softer, and which bears soft hairs.

The shoot gives rise to *branches*, which differ in several particulars from lateral roots. They grow obliquely upwards; the lowest are the largest and the oldest; they may branch in their turn. The region where elongation is proceeding is near the top of the shoots. In their growth they seem to aim at avoiding one another, as did the roots; this is another useful adjustment to needs. The latest-formed branches become very short indeed: finally they are disguised as *buds*. When you cut through one of these you find it to be a twig in a very compressed form and enfolded in leaves.

This brings us to the consideration of *leaves*, of which we found none on the roots. They are flat, with definite upper and lower surfaces; pay attention to the angle at which, in the garden, they place themselves to meet the rays of sunlight. The relative positions of leaf and bud are important and unvarying. With the exception of the bud which stands solitary at the end of a shoot-axis, the buds lie in the angles between the leaf-bases and the stems to which they are attached. Hence, when a bud develops we have a branch subtended by a leaf or a scar showing where a leaf had been; in the Wallflower many of the lower leaves have dropped off. Wallflower leaves are very simple in shape and are fixed to the stem by a narrowed portion. They are spaced out on the stem according to a clear plan; you can follow it by tracing a line from leaf-base to leaf-base, including the scars. No two leaves are at the same level; your line will wind upwards in a spiral. The part of a stem from which a leaf arises is often thickened and is called a *node*; the length of stem between node and node is an *internode*.

Amongst the plants you examine should be some bearing flowers and fruit. In these you find branches modified as flowering shoots, or *inflorescences*; sometimes every branch of Wallflower ends in this way. Again the region of growth is near the apex, and in an older inflorescence you may find at the same time very young buds at the top, open flowers in the middle, and fruits at the lowest levels of the specimen.

Examine one of the flowers. They are specially designed to carry forward the plant's life into a new generation. Each is attached to the axis of the inflorescence by a slender stalk or *pedicel*. In the Wallflower blossom, three very diversified series of members stand in whorls round a central body. The outermost whorl consists of four *sepals*; these are long, narrow leaves of dull reddish colour, and they fit close enough to act as a tube. They are not joined in the Wallflower, but in some flowers they are so, and a resemblance to a cup is apparent. Hence the whole group of sepals is known as a *calyx*.

Within the calyx stand four coloured *petals*, alternating in position with the *sepals*. Their lower portions are narrow and are confined within the sepal tube; the broad, free upper parts expand into the bright platform of the flower. This attractive circle is the *corolla*.

The next floral whorl in no way resembles leaves; it consists of six slender upstanding bodies, the *stamens*. Their stalks, or *filaments*, carry at the top the *anthers*, which are cases containing yellow, dustlike *pollen*. Possibly you expected to find four stamens. Look closely. Two of the stamens are shorter than the others, and stand each between two petals and at opposite ends of a diameter of the circle. The remaining four are grouped as two pairs which face each other cross-wise in relation to the shorter stamens. That originally there were only four stamens—two of which have divided—can be proved by more advanced study of their development. Before leaving the staminal whorl examine the little mound of green tissue which lies on the inner side of the base of each short stamen. It gives off sweet liquid which may collect in the little pouch lying near it: these are examples of *nectaries*. If you look back now to the outside of the calyx tube you will see their position indicated by a downward pouching of two sepals. The stamens are the male organs concerned in reproduction and together they form the *andrecium*, the man's part of the house (Greek *aner*, genitive *andros*—a male).

Compare the three whorls together, noting that the members of any one whorl alternate in position with those of the preceding (or succeeding) whorl.

In the centre of the flower rises the female reproductive organ, made up of *carpels*. It is the *pistil* or *gynecium* (Greek *gyne*, female), the woman's part of the house. In the gynecium you can make out three parts, which are often more distinct than in this flower. They are: (*a*) the long, slender tube at the base, the *ovary*; (*b*) a short neck, the *style*, arising from this, and (*c*) a two-lobed knob at the top of the style, the *stigma*. Cut open the ovary and you will find it is two-roomed, with a longitudinal partition; fastened along the edges of the partition are minute bodies, the *ovules*. These are the plant equivalents of eggs. The walls of the ovaries are formed of two carpels, which are somewhat suggestive of leaves.

Make a clean longitudinal cut through the centre of the flower; it is then evident that all the four whorls mentioned above spring in succession from the slightly enlarged top of the flower-stalk, known as the *receptacle* or *thalamus*.

Watch the changes which take place as the flowers fade. You find out that the ovary ripens into a *fruit* and the ovules mature as *seeds*. The fruits behave in an interesting way. As they ripen and dry up, the two walls—that is, the two carpels—break away at the base, curl outwards and upwards and finally leave the partition exposed, the seeds clinging for a time round its edges. Watch the performance in the garden; at a certain stage it needs only a windshake to send them flying far away.

Such is the plan on which is built an extremely simple plant. There are many no more complex, but on the other hand there are modifications by the thousand. Some of the essential terms have been given; unfortunately there are also a good many more of these.

CHAPTER II

THE LIFE-HISTORY OF THE BROAD BEAN

Vicia Faba, Linn.

THE family history of a plant, like the family history of a clan, may be of general interest, especially in its associations with men's ways of living and thinking. The useful though humble family of the Beans was sometimes honoured, sometimes disliked, often spoken and written about by the people who dwelt round the Mediterranean in the centuries B.C. The original wild stock from which man derived his cultivated forms is supposed to have had its home in North Africa or Asia Minor. We know that the people of the Bronze Age grew beans because they have been found in their lake dwellings. Beans were grown in ancient Egypt, and may have been used as food for the poorer classes and for domestic animals, but the priests regarded them as unclean and were careful not even to look on them. Both Greeks and Romans introduced them into religious feasts. By the Romans the Bean was called *Faba*, and the legend runs that the noble Roman family of the *Fabii* took their name from their bean-farms. White beans and black were used for voting, the white indicating approval. We learn from Pliny's writing (first century A.D.) of the custom then followed of bringing back from the field where crops had been sown a few beans—as a token that their corn would return home again unto them. Another practice he mentions sounds curiously modern. Bean-crops were ploughed into the ground just as they were about to bloom. "The sowing of the pulse," says Pliny, "in any ground, is as good as mucking into it, for it enriches it mightily" (cf. p. 155).

You may have heard of the superiority of peas and beans to other vegetables as a substitute for meat in a diet. We must find out what they contain which accounts for this.

We start with a glance at the Peas and Beans in our gardens. They are sown at various dates in spring. As they grow older, the Scarlet Runners must have their strings round which to twine, the tall-stemmed Peas must be staked, the French Beans form their little bushes, and the Broad Bean will stand up sturdy and independent. Flower is followed by pod; the seeds mature; the plant dies down. The whole life-cycle is completed within the season. Death of the plant follows the first seed production; the Broad Bean is an *annual*. Our task is now to follow its life from seed to seed.

GERMINATION

A bean, scarcely more life-like than a stone; from it a plant springs; there, is germination. It is our business to learn how this happens, and what the dead-looking bean demands in order that it may awake to life.

It is very desirable for a student to have a garden plot of his own; if that is not possible, he should ask to be allowed to observe somebody else's garden; gardeners are friendly folk, ready to show their good things and to talk about them. The young botanist should give consideration to what they say. He should keep in touch, month by month, with what is happening in the garden. The gardener prepares the ground for Bean and Pea crops by trenching it in the previous autumn or winter and leaving it rough, manure being added either then or (in a decayed state) in spring. The loosening and aerating of the soil will encourage the roots to range wide. The gardener expends great care on his seed-beds. The top layers must show fine *tilth*, that is, must be fine-grained and friable, free from stones; they must be raked loose and given a level finish. All this helps the progress of young shoots and roots. The depth at which seeds are planted is roughly determined by the size of the seed; peas and beans are set between two and three inches below the surface. The spacing must allow plenty of room for the adult plant. Broad Beans are hardy and the first of them can usually be sown in the garden in February.

Plants for close comparison with the Broad Bean should be reared in the garden. From the outset the student should definitely set himself to mark differences and likenesses, collecting and grouping facts which seem to be in relationship—always refraining from hasty conclusions.

The Broad Bean's companions in the garden should include the Garden Pea, the Sweet Pea, the French or Dwarf Bean and the Scarlet Runner Bean. The first may be sown from March onwards, the second in March or April; the last two not till May, as they require higher soil-temperatures for germination and the young shoots are too tender to bear frost or cold winds.

If Beans or Peas form one of the field-crops in your locality, get into touch with their owners and make acquaintance with the practices and problems of cultivation on a big scale. You must recognise this as applied botany, which is of importance in national economics.

The genuine gardener perhaps loves his seed-beds best of all. One day he sees them trim and lifeless; next morning he knows that living things are stirring there; the level is broken by narrow cracks and tiny mounds; something possessed of energy and apparently at no loss how to direct it is elbowing the soil aside and thrusting itself forth. It makes one want to sit down and see what happens. The rounded arches which lift themselves in the bean-bed take on a tinge of green almost before one has time to think of them as yellow. Up they come, till you find that each is a little curved stem; one end of this stays fixed, the other drags itself free from the soil and shows its leaf-clothed tip. Rather queer-looking, your rows of bean-hooks; soft yet the young things are, but they have done work, have overcome resistance—in virtue of their being alive. Continue to watch them; the stem gradually straightens; the green deepens; the leaves are spread to the sunshine.

When your sowings of other Beans and Peas come up, make close comparisons amongst them. Let this seedling work be the beginning of systematic records. Your entries should, at the season's end, constitute a chronicle of the main events in the life of any plant you are studying. It will give you excellent training in following up a line of inquiry; you will find, too, that having to make such entries in your book will compel you to look into the plant's behaviour more closely than you otherwise would have done: also, the welfare of the young plant depends on you, so you have a good chance of learning what its needs are.

Examination of Bean Seed

Make a thorough examination of the seeds of the plant. Examine them first as they come from the seedsman, dry and hard and somewhat shrunken, their brown scar (the *hilum*) indicating a point of previous attachment. Make well-labelled sketches at this and later stages, and enter with them notes on colour, texture, etc. Cut into the covering of the seed; it breaks away into pieces; within is a pale, very compact and brittle body: the whole seems hard and dry as it is possible to be. At a later stage in your work you might return to this stony-looking bean and experiment with it to see if there really is any moisture in it. Keep in mind that the beans you buy are not in their natural condition; if the gardener had not intervened they would have spent the winter months in damp soil.

Place beans in water. After a few hours of soaking, the coats (*testas*) swell up, become too big for the bodies they cover and fall into wrinkles. Continue the soaking and the body swells also, enough to stretch the coats smooth and taut. Wipe dry the outside of the plump bean and press it gently; you will see water oozing from a spot at one end of the hilum. With the hand lens you can make out a small hole there; this is the *micropyle*, which played a part when the ovule was fertilised (p. 35). Remove the testa; it comes off easily now, and in two unbroken pieces if you make a transverse cut about midway in the length of the bean. Note the change in thickness, and from a brittle to a tough condition. Close to the micropyle, the outside of the testa shows a darker triangular area, and corresponding to it inside is a pouched outgrowing of the wall. Examine what you have taken out of the testa; it is softer now and more flexible. From the concave side of it projects a conical prominence, which had lain within the pouch in the testa. The main mass consists of two flat lobes, easily separated and joined to the conical structure by very short stalks. Remove one of them carefully. They had concealed between them the prolongation of the conical axis, which curves over gently and ends in a cluster of delicate bits of tissue as revealed by your lens. Break the bulky lobe; its broken surface shows the water which it had absorbed. What each of these regions really is you will discover as you follow the course of germination.

Seedling Growth

You must arrange to have plenty of seeds available for examination at every stage in their growth; some of them in soil in the garden, in pots or in boxes, some in Sphagnum moss or sawdust, and a few on layers of wet flannel—all of them kept moist.

Perhaps the first thing you discover is that the triangular area near the micropyle is pushed open by the lengthening conical organ, which would be likely to get first share of the water sucked in and stored in the pouch. When the part of it between the lobes has grown a little farther, the apex shows as a group of leaves. The stalks by which the lobes are attached to the axis grow longer. Later you are confirmed in what you may have suspected—that the conical region is the first root (the *radicle*), the leaves represent the first and apical bud (the *plumule*), and the part connecting them the rudimentary stem. What are the big lobes likely to be? The whole of the contents of the seed constitutes the *embryo*.

The radicle, as is well seen on specimens germinated on flannel or in water, produces over a great part of its length numerous outgrowths finer than hairs but known as *root-hairs*; the extreme apex is free from them. Within the soil and the moss the radicle grows straight down, and the particles of soil adhere firmly to the root-hairs (Fig. 1).

The rudimentary stem is meanwhile growing; the plumule is still held between the lobes; growth is therefore going on in the length between the two fixed root and bud regions; the result is bound to be an increased curvature of the axis, and this arches itself upwards. The growth of the lobe-stalks pushes out the part from which they spring. The arched axis directs itself straight up; in working a passage out, its smooth, rounded surface is much less liable to damage than would be the soft, irregular plumule. There comes a time when, in each of the angles between the lobe-stalks and the stem, you can make out a bud; it helps to prove that these lobes, so ridiculously out of proportion to the embryo stem, are really leaves. They are known as seed-leaves or *cotyledons*. In other plants their leaf-like character is more apparent. The embryo stem has special names; the internode between the level of the cotyledons and the plumule is the *epicotyl*; that between the cotyledons and the root is the *hypocotyl*. The point where root passes into hypocotyl can be determined only by examination of internal tissues.

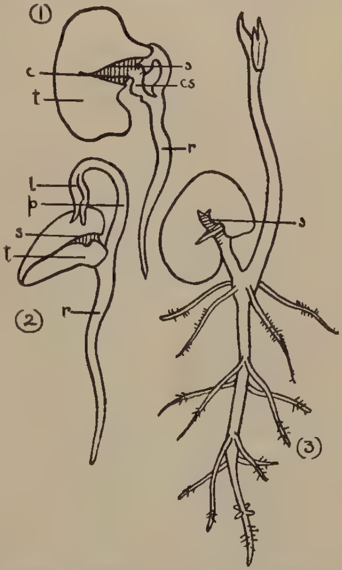

Fig. 1. Broad Bean Seedling

Three stages in growth shown. *c*, cotyledon; *cs*, cotyledon stalk; *t*, testa; *r*, radicle; *s*, split; *l*, first foliage leaf; *p*, plumule.

Directly after they reach the light, the stem and plumule assume a tinge of green which grows darker. The epicotyl, when above the ground, lengthens and straightens and the leaves unfold. As the radicle lengthens, secondary roots arise from it, each new one just above the zone of the root-hairs. What becomes of the cotyledons? They stay where they are, grow smaller and finally disappear, but they last a surprisingly long time.

With the Broad Bean's behaviour, compare that of your other Pea and Bean seedlings. In the French Bean you will find a striking point of difference: it is the hypocotyl instead of the epicotyl which lengthens most at first; and the effect of this is to carry the cotyledons above the ground. There they turn green, and live on as ordinary leaves for a time. The Broad Bean illustrates the *hypogeal*, and the French Bean the *epigeal* behaviour of cotyledons. The first foliage leaves which follow the cotyledons often differ from those of the adult plants. In studying your seedlings, keep a look out for such leaves; interesting theories are based on them.

GENERAL DIRECTIONS FOR EXPERIMENTAL WORK

(*a*) Be quite clear in your own mind as to what you hope to find out by your experiment; you will make it clearer to yourself if you set it out on paper.

(*b*) In setting up your experiment get the best apparatus you can; it need not be beyond you, however, to make a good deal of it. See that everything is absolutely clean; the presence of some foreign substance might make an experiment worthless. Be extremely exact over details, in making joints, in making apparatus light-proof, etc. Devise ways and means of your own; do not depend always on textbooks. Botanical experiments sometimes take a long time and demand unremitting attention; see that they get them. Plants must be watered regularly; events must be chronicled regularly, and so on. You must have great patience and be very watchful. Be careful to set up control experiments where required; as a rule you must permit only one factor at a time to vary. Your record-book should contain a full history of the experiment expressed in concise language. Make use of a tabular form of arrangement where it is suitable. Date your entries. Illustrate with sketches.

(*c*) Be as clear about the results you obtain as about your aims. Compare the two. You may at times be able to connect with previous experiments, and to arrive at generalised conclusions. Set these out in a paragraph of their own.

Verify your results as far as you can, and be careful to distinguish between results and inferences. Do not grudge the trouble of repeating experiments.

EXPERIMENTS WITH SEEDLINGS

Experiment 1. *Development of cotyledon buds.*—Cut off the plumules from one or two seedlings; watch how the buds in the axils of the cotyledons behave. Select more than one stage of development for your operation.

Experiment 2. *Depth of planting seed.*—Plant beans at various depths—say three, six and nine inches—several in each case. Use either large pots or the garden. Compare the average times that elapse before emergence from the soil, and also any differences in the plants. Do any fail to get through? What might be the causes of failure?

Experiment 3. *Effect of removing cotyledon.*—It was noticed that as the seedling grew larger the cotyledons shrank; try to find out if this is a case of cause and effect.

Select six plants growing in the same seed-box, which have emerged from the soil. Remove the soil with care from round two of them, and with still greater care cut off one cotyledon from each. From other two cut away nearly the whole of both cotyledons; the remaining pair leave undisturbed. The seedlings deprived of cotyledonary substance will, in their future development, fall behind the two which are intact. The cotyledons were food-stores.

What is the nature of this stored-up food? Break across a cotyledon and apply a little iodine solution to the surface. The tissue turns very dark blue; you would get the same colour by applying iodine to starch; there is starch in the cotyledon. It is not, however, the only substance present, although it constitutes more than half the mass. About twenty-five per cent consists of protein, which explains the high value of the bean as food. This protein will be discussed on page 204. Another matter which will require attention is the way in which food travels from the cotyledons to those parts of the seedling which need it (p. 119).

Experiment 4. *The energy of the seedling.*—The energy is very evident. You often see much more fragile-looking seedlings than those of Broad Bean forcing a passage through tough soil. This means work; the source of the power with which to do it will be looked for in a future chapter (Chap. ix). Meanwhile, you can test the strength of the young plant by packing over beans germinating in a pot or box a substantial plaster of clay or plasticine. Does the seedling manage to break through? Does it change its upward course if there is a chance given of growing round the edge of the obstacle? Remember that the shoot has not only to break the cover, it has to lift itself against the force of gravity. Can you fit up apparatus to get some measure of this growth-force?

Experiment 5. *Water is essential for germination.*—Take a dozen beans; soak half of them for twenty-four hours. Fit up two plant-pots, one half-full of dry sawdust, the other half-full of wet sawdust. Place the dry beans in the dry sawdust—three embedded and three lying on top; similarly, arrange the soaked beans in the wet sawdust. Cover the jars, but renew the air occasionally. At the end of two or three days the germination of those exposed seeds supplied with moisture can be seen. In the dry jar no seeds have shown signs of life. Leave the jars undisturbed for several days more. Again the dry conditions mean absence of growth, whilst in the moist the seedlings are thriving. Care will have to be taken that the jars are treated similarly as regards light and temperature. The only factor which is different is that of moisture; we may conclude from this that water is essential for germination.

Experiment 6. *The path by which water enters the seed.*—Probably the covering of most seeds gives you the impression that it is specially designed to prevent the passage of water; it may be leathery, hard, thick, etc. In extremes of heat and cold, the embryo is certainly safer if the seed is dry. Test soaked and unsoaked beans with high temperatures and low: devise your own methods. You will find that the power to germinate is more readily destroyed in the moist beans.

How does water get into a seed? The micropyle might be suspected. But what happens in those seeds in which the micropyle is closed, or in wheat, in which the seed-coat and the fruit-coat are fused and there can be no open pore? Try to find an answer in the following way. Take eighteen dry beans; close the micropyle in six of them (Set A) with rubber solution, leaving enough of the testa free to make an area equal to that in Set B. In six others (Set B) cover the micropyle and the hilum with the solution. In the rest (Set C) apply solution to any other part of the testa equal in area to that in Set B. Weigh each set. Put all to soak in the same shallow dish of water for twenty-four hours. Take them out in sets, and dry off every trace of water from the outside of the beans, being careful to squeeze none from the inside. Then weigh again. The Set C with the open micropyle shows far the highest gain. The other two sets have also gained a little, which shows that the seed-coat is not absolutely impervious. There is little difference between A and B, which indicates that the hilum is not a special entrance. Hence, we conclude that the micropyle is the most effective spot, but that water may enter over the whole general surface, including the hilum.

Experiment 7. *The temperature requisite for germination.*—Spring warmth brings spring growth, which suggests that we should inquire into the dependence of germination on temperature. Place three soaked beans in each of three pots of soil or wet sawdust. Pot A is to be kept in a room at ordinary temperature; pot B stands close to a radiator; pot C is enclosed in a tin box, where it is packed round with ice, which must be renewed when necessary. Shoots appear first in B and grow quickly; those in A are later and of slower but sturdier growth; probably those in C do not come up at all, or only after a long interval. Apply the same test to some other of your garden seeds—French Beans, for instance. You will find that they require a higher temperature than the Broad Bean. Thermos flasks may be used for experiments like this: thermometers are inserted through the corks; the seeds are suspended in bags; ice is placed in one flask.

The lowness of the soil temperature may be one of the reasons why seeds do not germinate in damp soil during the winter. Many experiments which have been carried out show that for any one plant there is a temperature below which its seeds will not germinate —the *minimum*; a temperature above which they will not germinate —the *maximum*; and a temperature which is the most favourable for the process—the *optimum*.

Experiment 8. *Oxygen is essential for germination.*—Animals we know must have air. Does the plant need it? The animal takes from air the constituent oxygen; if the plant needs air, what does it take from it—oxygen, carbon dioxide or nitrogen? At present we will ask for answers only on behalf of the germinating seed (Fig. 2).

Invert a gas cylinder, A, in a basin of water. Introduce some phosphorus into the air above the water in the jar by means of a bent wire; leave it for about a day. The phosphorus combines with the oxygen of the air, and the removal of the latter is indicated by the rise of the water through about one-fifth of the original air space in the cylinder. A now contains air minus oxygen. Remove the phosphorus and carefully slip into A a wire carrying four soaked beans. Place alongside A a second cylinder, B, which has not been treated with phosphorus. B will contain air with its usual amount of oxygen; put four soaked beans into this. Conditions are similar, except for the absence of oxygen in A. The result is that the beans in B germinate in the usual way, whilst those in A make a beginning (they contain a little oxygen within their testas) but soon cease growth. We may, then, form the opinion that oxygen is essential to the seedling, as it is to the infant animal.

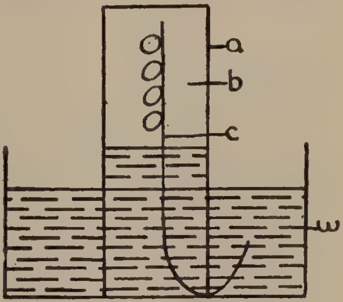

Fig. 2. Experiment to show that Oxygen is Essential for Germination

a, gas jar; *b*, space containing air deprived of oxygen; *c*, wire to which beans are attached; *w*, dish of water.

Experiment 9. *Respiration in germinating seeds.*—Perform an experiment on yourself as being an animal. Shake up a jar of lime-water to give it an opportunity of mingling with air; there is no visible change. Send the air you breathe down a tube into lime-water; the liquid becomes turbid with white particles which can be proved to be calcium carbonate ($CaCO_3$). The water contained lime (CaO); the air you breathed out must have carried a considerable quantity of CO_2 into the water, for the $CaCO_3$ is formed by the union of CaO and CO_2. Unrespired air did not contain enough CO_2 to show readily the formation of particles of $CaCO_3$.

Does the plant give off CO_2 as the animal does?

Provide two flasks with perfectly air-tight corks. Fill flask A half-full with well-soaked beans or peas. Do the same with B, but let the seeds be quite dry. Leave them corked up for a day or two. Test the air in the flasks for CO_2. This may be done by having ready a third flask, C, containing fresh lime-water, and also a cork provided with a delivery tube which will fit A and B. Remove B's cork and slip in the delivery cork, turning its tube into the lime-water. If flask B is slightly warmed by placing it near a radiator or even by holding it in the hands, bubbles of gas will pass over into C and can be counted as they enter the water. They do not affect the water; they consist of air unaltered by the presence of non-germinating seeds. Carry out the same procedure with flask A. Very soon the cloudiness of the lime-water indicates that the bubbles which entered contained much CO_2; this must have originated from the germination of the seeds in A.

The two experiments 8 and 9 taken together prove the essential identity of the respiration processes in the plant and the animal.

Experiment 10. *Plants give off heat in the process of respiration.*—Set up two jars, each provided with a tight-fitting cork, through which a thermometer passes into the interior of the jar. Fill jar A one-third full of moist, germinating beans or peas; fill B with similar seeds which have been killed by boiling, they too being moist, and at the same temperature as those in A to start with, as shown by the thermometer. Place the two jars in a box of sawdust to ensure the same external temperature for them. Leave them for a day or two. Jar A will show a higher temperature (probably 1° to 2°) than jar B. This is due to the respiration of the living seeds.

Experiment 11. *Measurement of root-growth.*—Make a closer examination of the radicle. A bean which is pinned to the under-surface of a cork and is left to germinate in the moist air of a bottle shows its parts very well. Look at a root about an inch long. The root-hairs are confined to a clearly limited zone (Fig. 3). A length, A, adjoining the seed, bears no hairs; another at the tip, B + D, bears none; between them is C, the hair-belt. D is a very short bit, more transparent than the rest of the root; this is the *root-cap*; its internal structure also differs very greatly (p. 190): it is well fitted to bore a way through the soil, being firm and pointed. It wears away gradually, but is renewed from above.

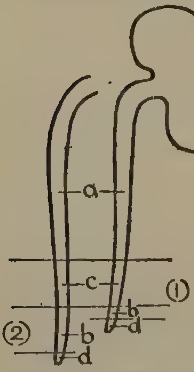

Fig. 3. To show Region of Growth in Root of Bean Seedling

a, without hairs; *c*, with hairs; *b* + *d*, without hairs; *d*, root-cap; *b*, the growing region.
(2) shows the increase in *b* after a period of growth.

Arrange an experiment to find out how the different regions behave as the root grows. Prepare a glass jar by lining it part way up with blotting-paper to be kept wet from a little water at the bottom of the jar. Select a bean having a straight radicle about an inch long. This is to be marked throughout its length with cross-lines one millimetre apart, the first being one millimetre from the end. Find out a quick and accurate way of doing this. You might lay the radicle along a ruler and apply at each millimetre mark a very fine thread wet with Indian ink—the thread being held stretched between the ends of a bent wire.

Measure the distance from the extremity to the highest mark. Having done your marking, arrange your bean, pinned to the under-surface of the cork in such a way that the radicle points directly downwards, within the jar. Put it away in darkness for a couple of days, as the root would naturally grow in darkness. Then examine. Find out the total increase in length; then look at the divisions. The apical section is still one millimetre long; the second millimetre looks very little different; the third has increased; the fourth and fifth divisions are the longest. There is no increase in the root-hair zone, and none above that. Zone B is evidently the place where growth in length is proceeding; the microscope will show us later exactly how it is carried out (p. 190). As zone B increases, part of its lower level passes over into the root-cap condition of D, whilst its uppermost strip ceases to grow, begins to form root-hairs and becomes part of zone C. The root-hairs at the top of C die off, so that C does not gain much.

As the tip creeps through the soil, it is accompanied by a constantly renewed set of root-hairs. In this way, these hairs are never broken away from their soil connections: they work till they die, and their work is taken up by young ones still closer to the root-tip.

To accommodate the growth in length, movement must take place, therefore a force is active. It tends to act both upwards and downwards; the root-hairs are holdfasts and therefore it is the root-cap which has to move. Applied close behind it, within the strip of enlarging tissue, the force drives the root-tip unerringly in a downward continuation of its original course.

Experiment 12. *Measurement of shoot-growth.*—Investigate the growth of the shoot in the same way as you did that of the radicle, using a plant about three weeks old growing in a pot. You will find that the growing region is considerably longer, extending for a fair number of centimetres from the tip.

Experiment 13. *Directive effect of gravity on seedling-growth.*—We return to the elementary idea that roots grow down and shoots grow up; it seems to be almost unnecessary to prove that this is a law of plant behaviour.

(*a*) Use a seed-box which has a glass side; the glass should be put in so as to slope inwards at the base; the roots of seeds placed near this side can be watched as they grow. Plant a number of beans close against the glass, the micropyles facing in various directions. In every case the radicles strike a vertical course downwards, and the shoots a vertical course upwards: they will accomplish this even if they have to bend through an angle of 180°.

(*b*) On the surface of the soil of the box place a seedling so that its plumule and radicle, already at least an inch long, lie horizontal. Make sure that the soil is moist; keep the plant from drying up by inverting a jar over it. In such experiments, the greatest care must be taken that the extreme tip is not injured in the slightest degree; otherwise, the normal response to directive stimulus will not be given. Let the experimental box remain in a warm and dark place for a couple of days. You will then find that the root-tip has turned down and buried itself, whilst the shoot-tip is reared aloft. You see then, that it is not only at the beginning of their career that the two apices choose a vertical path. It is clear also that it is not light which is guiding the plant.

How does a still older plant behave? Ask this from a straight, strong pot-plant of which the shoot has grown at least eight inches. Lay the pot on its side in a dark cupboard. In a day or two the tip of the shoot will have changed its position from horizontal to vertical. Set the pot upright; retain it in the dark; again the shoot succeeds in swinging its apex round through 90° in order to point upwards.

All these doings suggest very determined behaviour on the part of the two ends of the plant-axis. We know, however, that there is no purpose behind it, as there is in the case of an animal. We cannot say that the radicle is seeking water within the soil, and that the plumule is seeking light above the soil, for they have no knowledge to guide them.

Can the matter be explained as we explain a man's falling from a height in a line as nearly vertical as is possible, by saying that it is governed by the force of *gravity*? We know that this force, whilst acting mutually amongst all bodies, is usually manifested only when it tends to make all bodies move towards the centre of the earth—the largest body. Is it the pull of this force of gravity which regulates the plant movement? There are difficulties even in the way of regarding it as the direct cause of the downward movement of the root; and, of course, the shoot plainly defies the drag of gravity. In the case of our experimental seedling lying on the soil, the gravitational force must have been acting pretty equally throughout its length, yet only the radicle-tip turned downward.

Let us make some further observations, using young plants marked as for the root-growth experiment. Choose them with radicles about one inch long. Lay them horizontal on corks with about half the radicle projecting beyond the cork. Put the corks in a glass trough with enough water to maintain a moist chamber, and cover with a bell-jar. Exclude the light by covering with a box. Leave for a day or so. What do you find? That the curvature which carries the radicle-tip from the horizontal to the vertical is located precisely in that region in which the radicle is increasing in length. The growth there must therefore be unequally distributed round the axis, being greater on the upper side. The upward curvature of the shoot is also restricted to the growth-belt which, as we know, is more extensive than in the root; here the extension of the tissues is greatest on the under surface of the shoot. That which really has to be accounted for, then, is this disturbance of the uniformity of growth. The change in the direction of growth follows upon a *growth-curvature*.

This carries the inquiry on to the cause of the change in the distribution of growth. Has gravity anything to do with the matter at all? There is some influence operating, and always producing the same results. We know of one force, *gravity*, which acts vertically downwards (there may be others). We know of one which tends to make bodies move in a straight line away from a centre, namely *centrifugal force*.

There is an instrument called a *clinostat* by means of which we can eliminate the effect of a downward-pulling force such as gravity. Within the case (*a*) (Fig. 4) is a small clock. It carries with it a cylindrical axis (*b*) to which various supports may be attached, such as clips (*c*) which will hold a flower-pot.

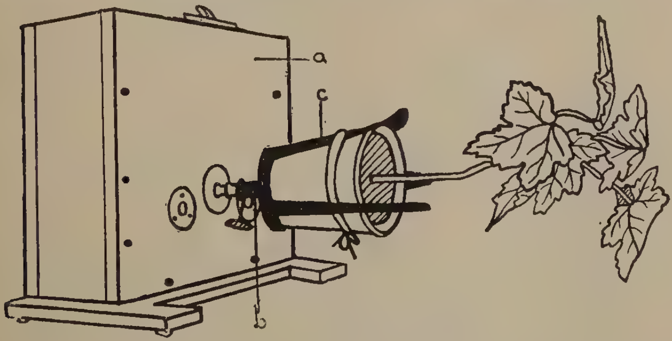

FIG. 4. CLINOSTAT (See text.)

Each revolution of the cylinder exposes every part of the circumference of the normal curvature region, equally, to the influence of the force of gravity. The *tendency* to increased growth travels round the plant-axis, and, therefore, gives rise to no curvature associated with unequal growth. This is true of both root and shoot. We have made gravity counteract its own doings.

There is a much harder problem to solve in finding out just how this force does the work. We can at least get a little nearer the answer. The curve is made in the growing region: is it there that gravity actually " touches " the root, as it were? It is not. If we cut off the extreme tip of the radicle before exposing it to the influence of gravity, in our experiment, there will be no curvature. The tip is, apparently, the receiver, the *receptor* of the influence. It can also be shown, by modifying the experiment, that the tip must be exposed for a certain minimum time if there is to be a response

So now we know that gravity affects the tip of the root, and that the effect of this is shown in the region of growth by a curvature. Between these two points there is a distance to be traversed. Theories have been offered to explain how this is done, but none is proved. Neither are we any wiser as to how the influence of gravity is definitely transformed into a stimulus of cell-growth at either the upper (in roots) or the lower (in shoots) side of the axis.

We may sum up by saying that gravity acts as a *directive* agent, indicating to root and to shoot the vertical direction. It is sometimes spoken of as a *stimulus* to which the plant responds; I do not know if that makes the matter easier to understand. All the plant movements which can be traced to gravity are said to be *geotropic*; in roots, we have *positive geotropism*; in shoots, *negative geotropism*; in leaves, *diageotropism.*

Experiment 14. *Directive influence of water on seedling-growth.*—There are times when the radicle disobeys the ruling of gravity. Fit up a shallow box with a netting of wide-meshed gauze; pack it with wet moss and plant beans in it. Hang it up in dry air so that the bottom is free and visible. The radicles in due course come out through the meshes. As if the new medium, the air, did not please them, they forsake the vertical direction and curve back to re-enter the damp moss. It might be said that this is to avoid light; eliminate this factor by keeping the box in a dark cupboard. The most likely influence now acting is the attraction of water within the seed-box.

It is still an unanswered question as to what is the mechanism and what the manner of its action which is strong enough to counteract the influence of gravity. One can picture thirsty roots in unevenly moist soil turning from one path to another when they "scent" water. The movement towards water is called *hydrotropism.*

Experiment 15. *How roots evade obstacles.*—Most seedlings have to make their way about in soil not specially prepared for them; what happens when a radicle or a plumule meets a stone? To find out, use your box with the sloping glass front, the seeds arranged close to the glass. Put stones directly in the paths which radicles and plumules would take as guided by gravity. The root-tip and the shoot-tip turn aside and grow round the obstacles without being injured.

Experiment 16. *Young shoots and light.*

A very obvious response on the part of older plants to light is familiar in the turning and bending towards the light, of a plant placed in a window. In this case gravity does not seem strong enough to keep the axis vertical. This bending of any part of a plant in response to the action of light is known as *heliotropism* or *phototropism.*

Experiment with seedlings. Have them in a box at least eighteen inches square. Cover this with a lid which will be light-proof except that in the centre of it there is a hole about two inches in diameter. Leave the arrangement undisturbed for a few days. On removal of the lid it will be seen that the seedlings under the hole grow upright, the others bend towards it in various degrees until those at the edges of the box are again upright. Evidently as far as the light penetrates it induces the seedling to curve towards it. Compare the responses in several kinds of seedlings.

The effect of light on plant-growth will be treated more fully on pages 200-207.

Experiment 17. *Young roots and light.*

Are roots as well as shoots affected by the direction in which light falls on them? In normal conditions the question does not arise, although aerial roots like those of Ivy might come into it.

Fit up a glass jar with a removable black casing, in which a narrow vertical slit has been cut. Arrange seedlings so that their roots are growing straight down into the moist air in the jar. No light must penetrate except through the slit, and that light should be as strong as can be arranged for. After a period, remove the covering, having marked the position of the slit on the glass. Results will vary widely according to the species of plant you have tested; you should compare a number.

Mustard is one plant in which the radicles diverge from the gravity line by a gentle curvature of the tip away from the light. Most roots are not affected. The root movement is an example of *negative phototropism*; the shoot exhibited *positive phototropism.*

CHAPTER III

THE LIFE-HISTORY OF THE BROAD BEAN (*continued*)

The Post-Seedling of Broad Bean

The plumule of the seedling makes quick progress when it reaches the light. As the hook straightens, the first leaves loosen a little; they are folded in two, face to face, each enclosing those younger. This is the opening of the first apical bud. To begin with, it is very soft, almost transparent; notice how this alters as it grows older, till, when the leaves are full-grown, the texture is firmer and the colour darker. The skin or *epidermis* of the leaf has not only thickened, but a waterproof substance has formed in it: before young leaves are equipped with this they run the risk of having their moisture extracted by the spring winds. This is one reason why buds are well protected. In a leaf like Holly, which hangs all the year round, the epidermis is even leathery.

The Sequence of Leaves

The first foliage leaves of the Bean seedling form an interesting series. Number one (Fig. 5 (1)) is a simple green blade, irregularly broken in outline at the top, which is left behind at the bottom of the stem and does not grow much. In the second (Fig. 5 (2)), the blade is divided into three segments, of which the middle one is slender and strap-shaped. In the third (Fig. 5 (3)), the two lobes of the previous leaf still adhere to the stem, but between them passes out a furrowed leaf-stalk to which they are attached. The stalk bears two large leaflets and terminates in a thread-like strip of tissue. Most of the leaves which follow are like this, but at times the adult leaf may have four or even six leaflets.

The Adult Leaves. The leaves of this plant give us much suggestive information. They differ from the Wallflower leaves: (*a*) in possessing a stalk (*petiole*) whilst the others are *sessile*; (*b*) in being divided into leaflets, and (*c*) in the presence of two triangular outgrowths from the base of the petiole, the *stipules*.

A petiolate leaf obtains an advantage by having its blade (*lamina*) carried out farther into the light. The midrib of the leaf is continued from the petiole: the petiole in the Bean is semi-cylindrical and deeply grooved on its upper surface. Water collected from the slightly cupped laminæ will run down these channels: does this seem to be of any service to the plant? The base of a petiole is often greatly expanded and may help to protect the young bud in its axil.

A leaf consisting of one blade is a *simple* leaf; a leaf which has several leaflets is *compound*. They exhibit many variations. In the Broad Bean the compound leaf ends in an insignificant filament just above the last pair of leaflets. In some plants the apex is an unpaired leaflet—occasionally it is so in the Broad Bean. Compare together the leaves of our Bean and those of the Garden Pea. In the latter there are again pairs of leaflets; but in the upper part of the leaf these are reduced to little more than the midribs of the leaflets. These are *tendrils*, slender cord-like structures which are capable of clutching at and winding round any object which is not too thick. The apex of the leaf-axis is also a tendril in the Pea. The Pea thus furnishes a clue to the variable tip of the Broad Bean leaf—sometimes a leaflet, sometimes a rudimentary tendril. Any part of a plant which is specially modified for climbing is a *tendril*.

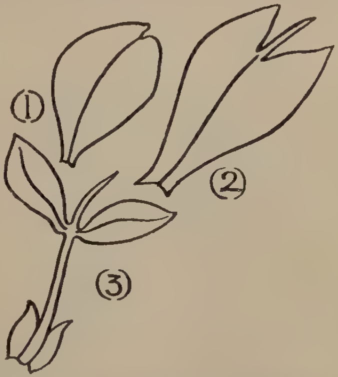

FIG. 5. FIRST FOLIAGE LEAVES OF BROAD BEAN

(1) First leaf; (2) second leaf; (3) third leaf. (See text.)

Stipules are of widespread occurrence among plants. If they are present, the leaf is *stipulate*; if absent, *exstipulate*. They are always paired outgrowths from the base of a leaf. Their existence is not very satisfactorily accounted for: why should two pieces of the leaf occur in that situation so often? The Broad Bean stipules are out of all proportion in the second leaf of the plant (Fig. 5); the leaf proper is a mere projection between them. In the adult leaf they are not much bigger; notice on the under surface of each one a purple patch; this is regarded as a nectarial gland; it is unusual to find these on leaves.

Stipules fulfil various functions, of which the Broad Bean illustrates two. (*a*) The young bud in the Bean is sheltered by the prominent stipules for a time. Very often, as in the Dock, they form a sheath in which the axillary bud is harboured. The huge membranous tent of the Rhubarb is formed of stipules and encloses for a time young stem and buds. (*b*) Stipules may take over the work of green leaves. The Pansy's stipules are very like divided leaves;

in the Bedstraw (*Galium*) they are so exactly similar to the strap-shaped leaves that they give a false impression of a whorl of leaves. (*c*) In some trees, e.g. Beech, the stipules are scaly, and their hard waterproof surfaces, overlapping tightly, are excellent protections for the delicate contents of the winter bud: they drop off when the bud opens. (*d*) In the False Acacia the stipules take the form of spines. No doubt the bud of the following season, lying between them and the stem, is thus saved from being eaten. (*e*) In Smilax the stipules are modified into tendrils.

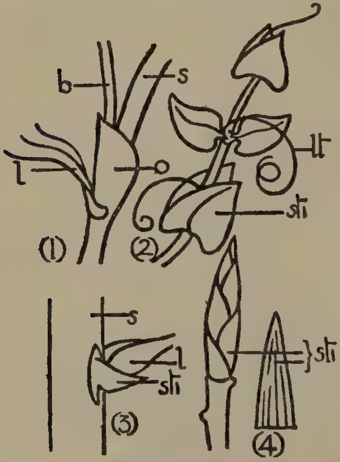

Fig. 6. Stipules

(1) Knotgrass: united stipules form a sheath encircling stem and its branch—an ochrea; (2) Yellow vetchling: stipules leaf-like; (3) False Acacia: spine-stipules; (4) Beech-bud: stipules are scales.

s, stem; *b*, branch; *l*, leaf; *o*, ochrea; *sti*, stipule; *lt*, leaf-tendril.

Some Leaf Modifications. These can be illustrated amongst the plants of the Family to which the Bean belongs. Amongst other specimens you should get the following:

(*a*) Laburnum. There are three leaflets attached by short stalks to the upper end of a long petiole. The stipules shrivel early.

(*b*) White Clover. Three leaflets rise close together at the top of the stalk. The stipules are small.

(*c*) Bush Vetch (*Vicia sepium*). There are many leaflets, three tendrils, small stipules.

(*d*) Sweet Pea. This has one pair of leaflets, several pairs of branched tendrils, small stipules and a winged stem.

(*e*) Wild Pea (*Lathyrus sylvestris*). There is only one pair of long, narrow, green leaflets; the rest are tendrils; the stipules are small, but additional green areas are provided in the broad, winged outgrowths from the stem.

(*f*) Yellow Vetchling (*Lathyrus aphaca*). This has no leaflets at all; all have been converted into tendrils, simple or slightly branched; the stipules, however, are like leaves.

Compare all the above with the Broad Bean which has medium stipules, no tendrils, a varying number of pairs of leaflets, a terminal filament replacing the terminal leaflet. Do not overlook the relation which plainly exists between diminishing leaf-surface and the compensating increase in green stipules and green stem-wings.

Venation and Leaf-form. Examine the leaflet of the Broad Bean.

Its outline is unbroken. Its central vein runs direct (i.e. without petiole) from its origin in the stalk to the apex of the leaflet. This vein gives off side veins; these again divide and this is repeated until a meshwork of the finest branches covers the whole leaf. The larger veins stand out well on the under surface, the finer are embedded. A leaf with vein distribution of this type is said to be *net-veined*.

With the veining is correlated the indentation of the leaf-margin, which in its extreme form gives rise to the leaflets of a compound leaf. Various series may be arranged to show the intermediate stages. Example 1: (*a*) Wallflower, (*b*) Oak, (*c*) Shepherd's Purse, (*d*) Rose. In (*a*) the outline is unbroken; (*b*) has a sinuate margin; (*c*) is cut deeply into lobes; (*d*) has been divided right down to the midrib which is now a stalk bearing separate leaflets. This is a sequence leading from a simple to a compound leaf. Example 2: (*a*) Garden Nasturtium, (*b*) Lady's Mantle, (*c*) Geranium, (*d*) Horse Chestnut. Again they run from simple to compound. But there is a difference, which arises out of the difference in the venation. In the first series, the secondary veins are given off at intervals along the main vein; this is *pinnate venation*. In the second, several great veins arise at one point; this is *palmate venation*. From these there are developed, respectively, *compound pinnate* leaves and *compound palmate* leaves.

Leaf-form is very helpful in classifying plants: you will find on pages 309, 310, a summary of the types and the terms relating to them. It will be useful for reference.

There is no certainty as to the causes which have led to the evolution of the various modifications of leaves—serrated edges, acute tips, leaflets, etc. You may read many suggestions, and you must be careful not to misread theories. You must not argue that because a divided leaf can be spoken of as being an advantageous shape because it allows a better distribution of light through a mass of foliage, that this supplies the *reason* for its being of that shape. The reasons are to be sought for in the history of its development—a very difficult task. One interesting theory may be mentioned. Certain leaves which are often found in tropical rain-forests have exceedingly long-drawn-out tips, known as "drip-tips." For a long time it was an undisputed belief that the special purpose served by the attenuated endings was to conduct away rapidly the heavy rain-water which fell on the leaves. When systematic research was directed on the matter, it became almost certain that this obviously likely function was of little, if any, importance.

Variation between First Leaves and Adult Leaves. The Broad Bean leaves form a good example; the first leaf is all stipules, the last leaves are compound (Fig. 5). As a rule the progression in form is from simple to complex. In the Runner Bean, the first two leaves are undivided and stand at the same level; they are in contrast with the compound alternate leaves of the full-grown plant. The Garden Nasturtium shows some beautiful points; its seedlings should be cultivated and watched. The first two leaves differ from all the others (Fig. 7): (*a*) they stand at the same level on the stem; (*b*) in shape, they are three-lobed, the apical lobe being very pronounced and the attachment of the petiole being near the margin of the rounded base; (*c*) they have two soft hair-like stipules, one millimetre long, which soon drop off. In succeeding leaves the lobes become less distinct, and the base becomes nearly straight. Finally, there is established the well-known leaf of peltate shape in which the petiole is attached to the blade at the back and towards the centre, exstipulate, and placed alternately with the others on the stem (Fig. 119).

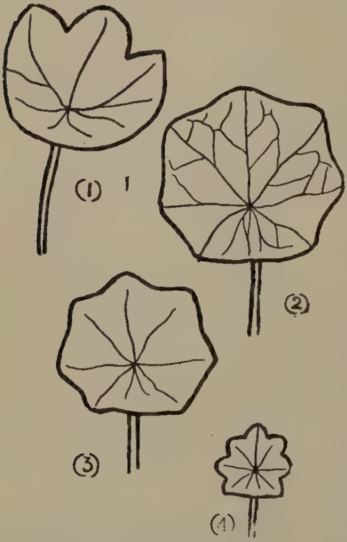

Fig. 7. Sequence in Leaves of Garden Nasturtium

(1) Mature form of the first two foliage leaves, which are opposite and stipulate; (2), (3), (4) immature leaves of adult plant, (4) being the youngest.

In the Greater Celandine, the first leaves are slightly lobed; the final are very much cut up.

The leaves in the Gorse seedling are nicely graduated. The sequence is: (*a*) undivided cotyledons; (*b*) a few trifoliate foliage leaves, of normally soft texture; (*c*) a number in which the side segments of the compound leaf grow smaller by degrees; (*d*) a stage when the leaves produced are simple, linear, flat; (*e*) leaves which are extremely fine and sharp-pointed, rounded and hardened into spines.

There is a theory which attaches great importance to the first developed leaves of a plant, as affording clues to the shapes of the adult leaves in ancestors of the plant. This is mentioned that you may think about it and watch for any evidence for or against it.

The *bud-chamber* of the Broad Bean is very snug: leaf-base, stipules and stem wall in a safe place where the bud can rest for a time. The buds have no special coverings; they lie as soft, pale-green balls in their green rooms. The question of the safe keeping of buds which have to last through long and possibly severe periods is of great moment; we shall have occasion to study it in other plant-forms. In a plant whose lifetime is limited to one season, the buds, though *naked*, are not in much danger.

THE STEM OF THE BROAD BEAN

The stem grows rather quickly, but remains strong enough to need no supports. In its lack of woody tissue it is a type of an herbaceous stem, to be compared with the *woody* type as seen in shrubs and trees. The stem of the Scarlet Runner is very long and thin, too weak to stand alone; the gardener gives it stakes or cords to which it may cling; it is an example of a twining climber. By pinching off the top of the shoot, he checks growth in length and gets a bushy plant, the branches getting the food supplies which would have gone to the apex. The terminal bud of the Broad Bean is often removed; it is the hiding and feeding place of the pest called the Black Aphis. This "topping" also improves the pods and hastens their ripening.

The stem of the Broad Bean is square in section; the angles are slightly winged, and from the angles at the nodes the leaves arise. Other examples of square stems are to be found in Mint and Hedge Woundwort. More frequently, stems are rounded; occasionally they are triangular, as in the Sedges.

The Broad Bean, with a soft herbaceous stem, is an *annual*, a plant which completes its history in one year. The Wallflower requires two years to carry its history to seed-production; it is a *biennial*; its stem becomes woody.

THE ROOTS OF THE BROAD BEAN

The first root of the Bean plant grows rapidly and keeps the lead over the laterals; it soon gets a very firm grip on the soil even in a flower-pot.

The roots of Beans in the garden plot should be examined at intervals up to the time of decay. At an early stage numerous swellings appear on them. They are signs that the plant is attacked by lower organisms which were present in the soil; their presence is most helpful as will be seen in Chapter XIII. On the Broad Bean roots they become as big as peas, are irregularly rounded and of pinkish colour (Fig. 8). They reach their full development about the time when the plant is flowering. After that they lose their plumpness gradually, and break up in autumn when the plant dies down;

the pieces crumble into the soil. Most of the plants belonging to the same Family as the Peas and Beans are liable to these root *tubercles* or *nodules*. This characteristic of the root system is of great importance in the cultivation of plants. You may find out some of the ways in which it is affected by treatment through your pot and garden Beans.

The root system of the Bean will spread widely if the soil is loose and open. Up to a certain point increase of water-supply will give more vigorous roots, but soil which is water-soaked for a long time will be so deficient in air that root-growth will be checked.

You might experiment on the Beans with various manures, noting not only the effect on the length of the roots but on the number of tubercles; note also any variation in the aerial parts if there is variation in the tubercles.

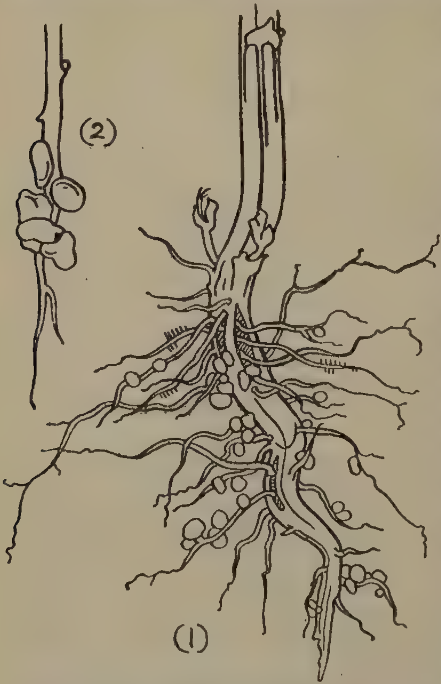

FIG. 8. ROOT SYSTEM OF BROAD BEAN
(1) Numerous nodules on rootlets of plant in July 1927; (2) nodules enlarged.

THE INFLORESCENCE OF THE BROAD BEAN

It is not easy to imagine a world without flowers; such our world once was, however, and it has been only by many steps taken forward that flowers have attained their present splendour. One gorgeous poppy, one big lily trumpet, one glowing rose—from far off any one of these draws our eye to it; it draws the insect also from far off. Other plants, by massing their many little flowers together, are equally successful in being attractive; we have the white umbrellas of tiny crowded Umbellifers, the dense-massed florets of the Sunflower, the grand spires of Larkspur.

The effect of the large flower is attained by the grouping of small flowers on a special branch. This flower branch constitutes an *inflorescence.*

The grouping varies in detail, and inflorescences have been classified first into two main groups and again into smaller, of which the relations are simple.

Group A. (Fig. 9.) The inflorescence of the Broad Bean belongs to the simplest type in this group. It being a branch, you find it as usual in the axil of a leaf. The axis is elongated (its specialised name is a *rachis* or *peduncle*) and bears flowers throughout its length, each in the axil of a small leaf, known as a *bract.* The lowest flowers open first; the apex goes on growing, and fresh flowers appear near the apex. Each flower is provided with a little stalk, the *pedicel.* The pedicels are about equal in length, so the flowers stand at different levels. Such an inflorescence is a *raceme.* Most racemes are upright; Laburnum is pendulous.

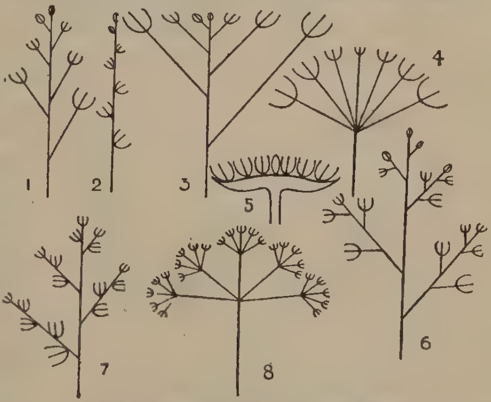

Fig. 9. Racemose Inflorescences

(1) Raceme; (2) spike; (3) corymb; (4) umbel; (5) capitulum; (6) compound raceme (panicle); (7) compound spike; (8) compound umbel.

From the raceme may have been derived the *spike* (e.g. Plantains), in which flowers are sessile on the peduncle.

If the pedicels of the lower flowers lengthen in such degree as to bring all the flowers to the same level, we have a *corymb* (e.g. Candytuft).

A new variation arises if the peduncle does not lengthen between the origins of the flowers; a raceme which by this change assumed a " telescoped " appearance would give an *umbel* (e.g. Ivy).

A spike similarly shortened would give a *capitulum* (e.g. Daisy). The florets of the capitulum are held together by a cup or *involucre* of bracts. The bracts of the individual flowers are sometimes present as little scales amongst the florets.

If the peduncle branches, the inflorescence is compound, e.g. a compound spike (Wheat), a compound umbel (Fool's Parsley). A compound raceme is called a *panicle* (Lilac).

The *catkin* of the Willow, etc., is a pendulous spike of unisexual flowers. The *spadix* is a thick, soft, upright axis of unisexual flowers, which may be enclosed in a conspicuous bract, or spathe, as in Cuckoo-pint (*Arum maculatum*) (Fig. 62).

All the inflorescences mentioned above are included in the *racemose* group, the chief characteristic of which is the *acropetal succession* shown in the unfolding of the flowers; that is, they either succeed each other from below upwards (raceme), or from without inwards (corymb). As the growing point remains capable of extension, the group is also called *indefinite* or *open*.

Group B. (Fig. 10.) These are the *cymose inflorescences*. In them the first flower arises at the top of the main floral axis, which then stops growing. There may be no more flowers, in which case the inflorescence is spoken of as *solitary* (e.g. Tulip). This type is sometimes placed alone, outside both groups, the *flowers* being described as solitary. A *cyme* is a *definite* or *closed inflorescence*. Flowers later than the first in a cymose inflorescence are the terminal buds of branches rising in the axils of leaves at levels lower than the first. In case (*a*) one secondary branch leaves the main branch and terminates in a flower; then a flowering branch is given off similarly from this secondary branch; this may be repeated. Sometimes the buds which develop are all on one side of the stem, sometimes on alternate sides. This type of cymose branching is a *monochasium* (e.g. Forget-me-not). In (*b*) the main axis gives off two secondary flowering branches; each of these in turn gives rise to two, and this may be repeated. In each case the branch terminates in a flower. This is a *dichasium* or forked cyme (e.g. Stitchwort). In (*c*) more than two secondary branches rise from the first. This is a *pleiochasium* (e.g. Elder).

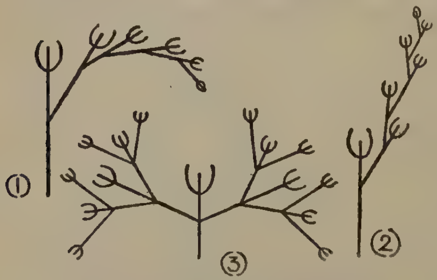

FIG. 10. CYMOSE INFLORESCENCES
(1) Monochasium; (2) monochasium; (3) dichasium.

The above are straightforward types. In reality there are many combinations and modifications of them; for example, an inflorescence may begin as a raceme and pass over into a cyme.

THE FLOWER OF THE BROAD BEAN

In general appearance the flower of the Broad Bean is a great contrast to that of the Wallflower. The latter is radially symmetrical; the former is balanced only on two sides of one plane. This plane cuts centrally through the flower and also through the peduncle to which the flower is attached. Flowers which possess this bilateral symmetry are called *zygomorphic*; those with radial symmetry, *actinomorphic*.

The *calyx* is a green cup of which the lip is cut into five teeth, a sign that it is probably formed from five sepals. They are joined together; the calyx is *gamosepalous*. One tooth stands in the medial plane, on the side farthest from the axis—the *anterior* position.

The irregular look of the flowers is given by the varied shapes of the petals, there being a fancied resemblance to a butterfly. Before you dissect the flower, notice that the largest petal stands up boldly, in the *posterior* position on the medial plane, and between two calyx teeth. These points of relative position are necessary for making a ground plan of the flower; this is a case in which most careful drawings must be made of every part of the specimen. There are five petals, which are not joined together—a *polypetalous corolla*. (*a*) The large *standard* petal is very noticeable, white with dark-coloured streaks converging towards its base. The standard folds together enclosing all the other petals when the flower is in the bud stage. (*b*) Two side or *wing* petals stand pressed together in such a position that their rich dark brown is thrown into strong contrast with the light background of the standard. (*c*) Within the wing petals are the remaining two. These anterior or lower petals are united lightly to form a narrow boat-shaped structure, the *keel*.

The fitting together of (*a*), (*b*) and (*c*) is most ingenious. The keel petals are slightly ridged and dinted; the wings have corresponding folds which lock down quite tightly into the keel. Presently we shall see how the mechanism works.

The Andrecium. This, too, is cleverly devised. Take it apart carefully. You recognise the ten anthers, but only one of them seems to be part of a normal stamen; that one is placed at the top of a long filament. The filaments of the other nine are free only for a short distance below the anthers; then they fuse together into a thin sheet; this is curved into trough-form. It fits into the keel, where the free parts of the filaments curve so as to carry the stamens into an upright position at the tip of the keel. The filament of the odd stamen is placed as a lid-like covering for the trough. Nectar is secreted within the trough.

The Gynecium. Within the staminal trough lies a pale transparent body which at once suggests the shape of a bean-pod. It is prolonged at the free end into a style, tufted with hairs near the tip. Within the ovary are the ovules; it is formed from one carpel. The stigmatic tip takes a place among the stamens, curving so as to point upwards.

How the Mechanism acts. Use a flower which is just mature, and which looks as if it had not been disturbed. Press with a bit of bent wire at the same time on the two sides of the folded wings. As they move downwards they carry with them the keel; outwards and upwards spring the contents of the keel. Next watch a flower to see how nature does that which you have done. If you wait long enough you will probably see a bee arrive. In quest of what it knows is hidden within, it alights astride the folded wings and grips them on each side with its legs. Down go the wings and keel, and up come the stamens and stigma. The bee does not disturb itself; it pushes its long tongue under the loose stamen and sucks up the sweet juice which lies at the far end of the staminal trough. Then off it goes to another flower. Probably it is dusted over with pollen. As the pollen is shed it collects in the keel and when the parts are moved by the bee, some of it is swept out and over the bee by the brush of hairs on the style. The bee's next visit may be to a flower which is in the same stage as the first, in which case more pollen is collected. On the other hand, the bee may visit flowers in which the stigma is mature; some of the pollen brought by the bee will very likely adhere to the now moist stigmatic surface. In this way not only one flower, but one plant, may be pollinated from another. This is a good example of *cross-pollination.*

The arrangements in the Bean flower provide shelter from rain for the pollen, which in many cases is injured by moisture. After the bee departs the keel slips back into place; so, the pollen is distributed a little at a time, which is economical. Finally, the nectar is reserved very effectively as a lure for such insects as can reach it by the path which brings them into contact with the pollen.

Within the Family to which the Bean belongs there are several modifications of this pollen-distributing scheme. The grouping of the stamens is taken as a character distinguishing two groups of flower-forms. In **A**, the stamens are arranged as nine united and one free, as in the Broad Bean—the *diadelphous* condition. Nectar is present. Examples: Clover, Lady's Fingers, Bird's-foot Trefoil, Sainfoin, Wild Vetches, Scarlet Runner Beans, Sweet Pea, Garden Pea. In **B**, the stamens are all united into a tube, the *monadelphous* condition. Examples: Lupin, Gorse, Broom, Restharrow, Laburnum. In these nectar is absent and the flowers are visited for pollen.

When the bee leaves the Bean flower the keel springs back into its original position; the same happens in White Clover, Peas and others. In Gorse and Broom the action is different. To begin with, style and stamens are curved and are kept under tension within the keel, which is joined along its upper edge into a tube. This tube splits when the bee presses down on it, and the anther tube along with the stigma uncurls with a strong upward throw against the bee. When the insect moves away there is no return of the parts to their first position. The drooping keel and exposed stamens betray those flowers which have been rifled. In the Runner and French Beans the keel and style are coiled. The flowers of White Clover are so short-tubed that short-tongued insects can reach the nectar. In Lupin and others the stamens do their own work of pushing out the pollen. The inflorescence of Laburnum is erect as long as all the flowers are in bud form; when the first flower opens it becomes pendent. This brings the standard petal into the lower position (it had been upper in the erect raceme), and all the adjustment of the petals, etc., is thrown wrong. Adjustment is made by the stalk of each flower twisting through an angle of 180°. Again the standard is flying, and again the bee has its alighting platform ready for it.

GRAPHIC SUMMARIES OF FLOWER

It is very useful sometimes to have a ground plan of a flower, in which the relationship of the parts can be seen at a glance. It is a form of graphic shorthand. Below is a specimen of one representing the Broad Bean (Fig. 11).

Your *floral diagram* (the ground plan) is a representation of the imaginary transverse section which you would get if you could cut through all parts of the flower at once. It should show the relative positions of the floral whorls, and of the peduncle, bracts and bracteoles (secondary bracts). It should also indicate whether or not members are united, the nature of the symmetry, and the placentation (p. 34) as seen in the cross-section of the ovary. The positions of the parts are set out on concentric circles, one for each level, so that, for example, if you have six petals in two whorls you must give them two circles.

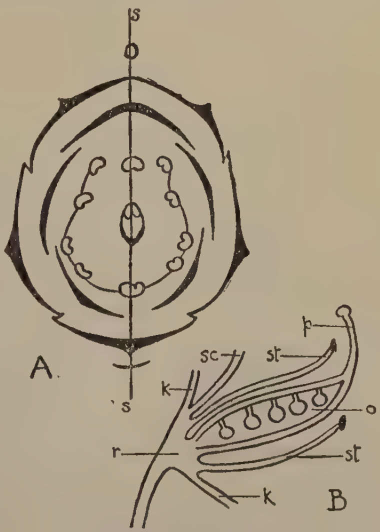

FIG. 11. FLORAL DIAGRAM AND LONGITUDINAL SECTION

A, Floral diagram; B, Section along line *s*——*s*.

k, sepal; *sc*, standard petal; *st*, stamen; *p*, style; *o*, ovary; *r*, receptacle.

Another useful bit of shorthand is the *floral formula*. The usual symbols which are employed are:

P	perianth (p. 47).
K	calyx.
C	corolla.
A	andrecium.
G	gynecium.
( )	parts joined.
∞	number of parts indefinite.
+	connects two like whorls.
$\underline{G\ 5}$	superior gynecium of five carpels (p. 33).
$\overline{G\ 3}$	inferior gynecium of three carpels (p. 33).
$\overbrace{C(5)\ A5}$	stamens fixed on corolla.
3–5	means varying between 3 and 5.

The following are sometimes used:

⊕	actinomorphic.
↓	zygomorphic.

Examples:

Wallflower	$K2+2\ C4\ A2+4\ \underline{G(2)}$
Broad Bean	$K(5)\ C5\ A(5+4)+1\ \underline{G1}$
Bluebell	$\overbrace{P3+3\ A3+3}\ \underline{G\ (3)}$
Lesser Celandine	$K3–6\ C4–14\ A\ \infty\ \underline{G\ \infty}$
Wheat	PO or 2 reduced $A3+0\ \underline{G1}$
Coltsfoot	K modified $\overbrace{C(5)\ A(5)}\ \overline{G(2)}$
Sycamore	$K5\ C5\ A8–12\ \underline{G2–4}$

It is very necessary to be sure about the relative levels at which the whorls stand. Make a sketch from a vertical section. Cut your flower as nearly as possible into two symmetrical halves. You must represent by clear strong lines in your diagram the exposed edges of the structures which are cut through; sometimes this is all that is put in, but you may, if you like, sketch in the back outlines more faintly.

Make such a section of the Broad Bean flower; the cut must pass through the medial plane. Compare it with one of the Wallflower; there is a fundamental difference. In Wallflower, the receptacle on which the members are inserted has remained slightly convex, which was its youthful form. In succession on it, upwards, stand sepals, petals, stamens, ovary. The position of the last is selected as the standard for comparison in level; as it stands at a higher level than the others it is said to be *superior* and the flower is *hypogynous* (Fig. 12 (1)).

Imagine that the central region of the receptacle stops growing before the circumference and that the latter area carries up with it the developing whorls of sepals, petals and stamens whilst the gynecium stays behind. This gives rise to a shallow cup on the edges of which are the three outer whorls and at the bottom of which is the ovary. Such a gynecium is still spoken of as *superior*; the flower is *perigynous* (Fig. 12 (2) (3)). To this group belongs the Broad Bean.

The third stage in this evolutionary change will be illustrated in the Daffodil. The growth of the receptacle border far outstrips that of the centre; it finally overtops the gynecium and closes over at the top, the *thalamus* (*receptacle*) walls fusing with the ovary walls. We see then all the three outer whorls seated immediately above the gynecium. The latter is then *inferior* and the flower is *epigynous* (Fig. 12 (4)).

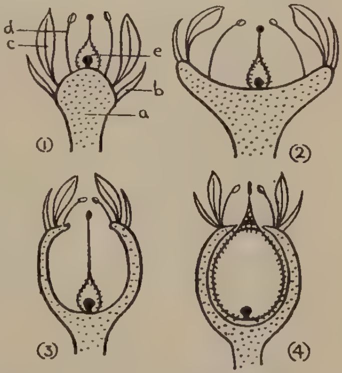

FIG. 12. RELATIVE POSITIONS OF FLORAL WHORLS

(1) Hypogyny; (2) Perigyny; (3) Extreme perigyny; (4) Epigyny.

a, receptacle; *b*, calyx; *c*, corolla; *d*, stamen; *e*, ovary.

FERTILISATION

This is a difficult subject and we will take it here only in outline. We have seen some of the means by which it is ensured that pollen shall be deposited on the stigma. Examine the pistil again. Open the ovary; it splits readily along one side, and you can fancy it to be a tiny leaf folded along its midrib, the ovules being attached along what would be the edges of such a leaf. This idea quite possibly has a foundation in historical fact; it is believed by some botanists that ovaries originated by the doubling of a foliage leaf. The tip of the leaf would then be represented by the style and stigma. In existing plants, the ovary cavity may be continued into the style; in others, the centre of the style consists of loose tissue. The extreme tip of the original leaf would become modified when it assumed the special function of receiving and retaining pollen. All this fits quite well a simple gynecium like that of the Bean or the Pea. The edges of the theoretical leaf, united along what is called the *ventral suture* of the ovary (the midrib forming the *dorsal suture*) became thickened. The two lines of ovules arose as outgrowths from this band of tissue, which is called the *placenta*. The arrangement of the ovules within the ovary is styled *placentation*; when the ovules are situated along the edges of a carpel the placentation is *parietal* (or *marginal*, a term reserved for an ovary of one carpel). Each ovule is fixed on a miniature stalk (the *funicle*). One of the difficult questions in botany is the reason why ovules came into being in the first instance; the question still awaits someone to find the answer.

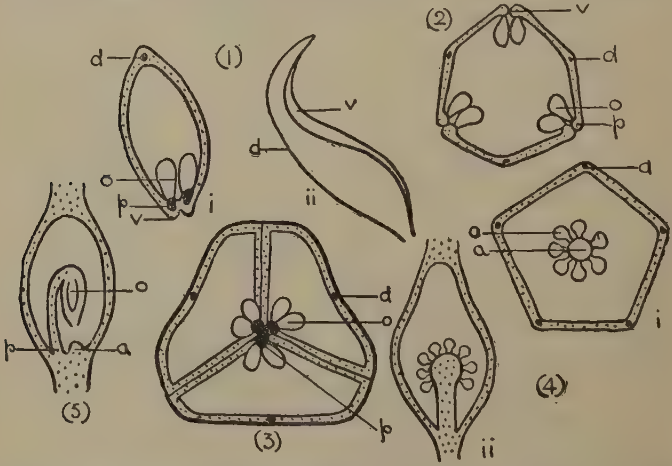

Fig. 13. Placentation

(1) Parietal (one carpel, marginal type): (i.) transverse section of Broad Bean; (ii.) closed ovary of Broad Bean; (2) Parietal (several carpels), Violet; (3) Axile, Bluebell; (4) Free central: (i.) Transverse section of Primrose; (ii.) Longitudinal section of Primrose; (5) Basal, floret of a Composite.

d, dorsal line (midrib); *v*, ventral suture; *p*, placenta; *o*, ovule; *a*, axis.

An ovule begins at a certain spot in the placenta as a special mass of cells; very important divisions of the mass of tissue take place. One microscopic unit of matter there is of more importance than any of the rest; it is the *egg-cell*. There, for a short time, the egg-cell lies embedded in the small pile; then, from the placenta, two folds of tissue grow upwards and envelop them all. They cover in the little body nearly completely; a very small aperture is left at the apex. This is the *micropyle*, which we saw in the Bean seed (p. 8).

Now let us see what happens to the pollen grain which the bee left on the stigma. The stigma, when ripe, is sticky with an excretion of its own, and the pollen grain stays there. It begins to grow, which is surely surprising. It feeds on the liquid on the stigma. It is quite easy to get sight of pollen grains growing; they will do it readily in a ten per cent sugar solution, which you can arrange for viewing in a watch-glass. A long fine tube grows out at one point in the wall of the grain; on the plant, it proceeds, with no deviation, down the style. Thence it makes its way along the placenta, and turns away from it into the cavity, seeking out in a seemingly knowing fashion the micropyle of an ovule. By this little doorway it slips in. Inside, the tip of the pollen tube allows to pass out specialised portions of the substance within the tube. *The most important of these unites with the egg-cell.* This fusion of two microscopic but highly specialised pieces of living matter is essentially the process of *fertilisation.* It is the end and aim of all the plant's preparation—the creation of a new individual. The microscope reveals some wonderful details involved in it, but there are still secrets which baffle the scientist.

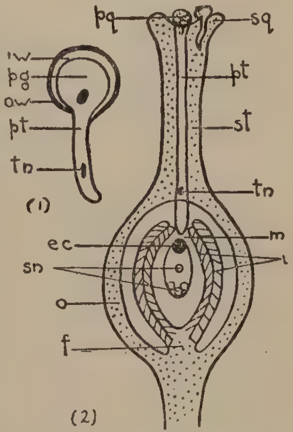

FIG. 14. FERTILISATION

(1) Germinating pollen grain; (2 Pollen tube penetrating to egg-cell.

o, ovary wall; *st*, style; *sg*, stigma; *i*, integuments; *f*, funicle; *m*, micropyle; *ec*, egg-cell; *sn*, subsidiary nuclei; *pg*, pollen grain; *pt*, pollen tube; *tn*, fertilising nucleus of tube; *ow*, outer wall of grain; *iw*, inner wall of grain.

FRUIT FORMATION

After an ovule is fertilised it is a *seed*, within which the fertilised egg-cell grows, and divides, and ultimately is transformed into the *embryo* or seed-plant. The ovary itself with its seed-contents becomes the *fruit*, and its wall is called the *pericarp*. Fertilisation stimulates growth not only of ovules but of ovary walls, and the bulky structures seen in many fruits are the results. There is the greatest variety amongst them and in the way they act when the seeds are ripe. The fruit of the Broad Bean furnishes a simple type of fruit. Notice how, as it matures, all the floral parts wither except the calyx, which is *persistent*. When ripe, the walls become dry and hard, and at last split open down both sutures. This type of fruit is a *pod* or *legume*; it belongs to the group of *dry, dehiscent* (opening) fruits.

Many of the plants belonging to the same Family as the Sweet Pea show very well a successful device for scattering their seeds; this is desirable, in order that seeds may get better chances of space in which to grow up. The tissue in the walls of the pods, e.g. in Broom, Gorse, Sweet Pea, dries unequally. When the tension in some of the strips passes a certain point the strip contracts, the valves of the pod fly open and curl back suddenly; in some pods, such as Lupin, the valves twist quite tightly. The seeds may shoot out several feet. Look out for this amongst the Gorse on a warm day; experiment by drying some pods and measuring the distance the seeds are jerked away.

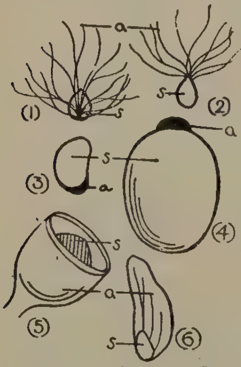

Fig. 15. Arils: Outgrowths from Seeds

(1) Willow; (2) Willow-herb; (3) Pansy; (4) Castor Oil; (5) Yew; (6) Pine.

The seeds of Gorse are carried fair distances by ants. Each seed bears a small oil-body at one end; this is much liked by ants. They set out to drag whole seeds to their nests; sometimes they drop them on the way and leave them; sometimes they eat the oily bit and forsake the rest. Ants make use of cart tracks on the moors: instances have been found in which lines of Gorse bushes have followed the tracks, probably thanks to the ants. The name *aril* is given to outgrowths from seed-coats; they have very diverse forms. As examples should be compared the tufts of hairs on the seeds of Willow and Willow-herb, the ridge on Pansy, the oil-bodies on Gorse and Castor Oil, the fleshy cup of Yew, the "floats" on Pine, and the orange-coloured envelopes of the seeds of the Spindle-tree (Fig. 15).

Closing History of the Bean Plant

Allow some of your garden crops of Beans and Peas to pursue their existence to the end without removing flowers or fruit. Record what happens to all parts including the seeds. Put marks at the places where seeds fall and see that they are not disturbed throughout the winter. Do they get buried in the soil? Do they germinate in autumn or lie waiting for the spring? The seed of Chickweed germinates almost as soon as it drops into the ground, but for most seeds there is a distinct period which is a resting phase. The seed, with its enclosed young plant, is the safest form in which the winter can be spent; it is the extreme *hibernation* form.

Our study of the Broad Bean is finished for the time. Do not miss this great truth which emerges from it: there has been the death of an individual, but the individual has left part of itself in the seed: there is continuity of living substance: there is *something which has not died.*

CHAPTER IV

THE INSECT AND THE FLOWER

THE association between these two representatives of the animal and the plant worlds, and the tale of how it has arisen, form one of the most interesting themes in nature. Their evolutionary histories have run parallel, they have kept pace with each other, incited each other at every step.

Let us take the flower first. It is a general opinion that the first flowers were small, greenish, insignificant, and that their pollen was distributed only by wind. We have plants which still keep this habit, such as Grasses and Plantains. They produce pollen in great quantities; much of it is wasted; the pollen is dry, smooth and adapted for flotage. Stamens and stigmas in these wind-pollinated plants are prominent—widely spread in order to scatter or to capture. Insects existed in that age of primary flowers, but there was amongst them none of the highly intelligent creatures having elaborate mouth-parts with which we are familiar.

The animal-plant interplay began when insects found pollen good to eat. Then, if some flowers happened by virtue of size or a tinge of colour (probably yellow) to be more conspicuous than others, insects would see these first and visit them more frequently. There would be a chance of their carrying some pollen on their bodies. If it were true then, as it is so often now, that pollen is more efficacious if transferred from one plant to another, then those flowers would have better seed-bearing chances than the others. This may have been the way in which the brightly coloured flower made its beginning. No doubt these flowers were at first very simple—regular, open, shallow. The chance for the seed was still precarious, hence they had many stamens and many carpels. The next step forward was probably made when a sugary liquid began to ooze out of the tissues at the bottom of the flower and to collect inside it. The insects liked this even better than the pollen, and the nectar-flower's success was assured. So far the feast was free, and easy of access to every visitor; naturally the supplies of the dainty were soon finished. But one day a flower chanced to have its nectar slightly hidden by some outgrowth and it escaped for a while. In time an insect with a little more intelligence and perseverance, and perhaps with a mouth better fitted for the little job, got at it, after travelling diligently over all the stamens; it carried away more pollen than usual. Both plant and insect were in the end just a little ahead of their competitors for subsistence. Multiply instances of this happening, and pile up the infinitesimal additions to the original modification of the nectar-bearing part; accept it as being likely that the changes would be inherited. You may be able to visualise the two long parallel roads, ages long, down which insect and flower have travelled abreast, acting and reacting one on the other, till at last there was evolved the strong, clever bee, having mouth-parts specially modified for getting its nectar-food from the recesses of Larkspur or Columbine. It sounds like a prolonged battle of growing wits, both sides gaining huge advantage.

The flower progress from wasteful simplicity of form to a complexity which proves truly economical—from Buttercup to Monkshood—is fully illustrated throughout this book. Some elementary information about insects may be introduced here.

The principal Orders of Insects which are concerned in the pollination of flowers are:

(1) *Coleoptera* (the true Beetles).
(2) *Diptera* (Flies).
(3) *Hymenoptera* (Bees and Wasps).
(4) *Lepidoptera* (Butterflies and Moths).

The modifications of the structures which surround the insect's mouth form the subject which concerns us most in connection with flowers. The mouth of the Cockroach, a mouth fitted for biting, is one of the least specialised, and reference to it may make it easier to understand the mouths of the higher insects. If you have studied the Crayfish you will be able to trace resemblances to the head-parts of that animal; Fig. 16 is a very diagrammatic plan of the mouth-parts of the Cockroach.

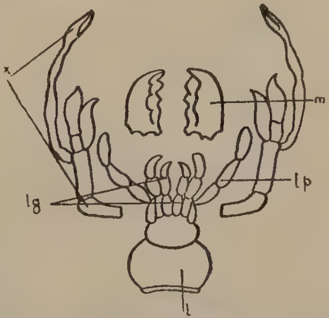

Fig. 16. Mouth Parts of Cockroach (after Dufour: simplified)

m, mandibles or hard jaws, biting organs; *x*, maxillæ, soft jaws; *l*, labium, which has arisen by the partial fusion and subsequent alteration of a pair of appendages placed behind the maxillæ; *lp*, labial palps, jointed extensions of the labium; *lg*, ligula, processes from the front of the labium fused near their origins.

M. are the mandibles or hard jaws, biting organs.
X. are the maxillæ, or soft jaws.
L. is a centrally placed structure which has arisen by the

partial fusion and subsequent alteration of a pair of appendages placed behind the maxillæ. It is the *labium*.

Lp. are the *labial palps,* three-jointed extensions of the labium.

Lig. is the *ligula.* It consists of processes from the front of the labium which are fused near their origins.

(1) The Beetles have mouths most like that of the Cockroach. They can bite and chew, but they can also lick up nectar from open receptacles. The principal Beetle which wanders about in British flowers is a little bronze-black one.

(2) Flies have piercing and sucking mouths. The piercing instrument is a tube formed from the labium, in which lie needle-like processes. The so-called "tongues" are less than four millimetres long except in Hover-flies and Bee-flies, which are more advanced in this respect. The short-tongued flies take nectar from flowers where it is freely exposed—e.g. Hawthorn, Saxifrages, Umbellifers. Hover-flies are often seen on the Speedwell, and Bee-flies on Primrose.

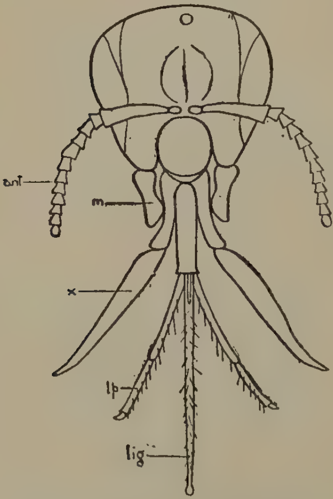

FIG. 17. HONEY BEE: HEAD OF WORKER

ant, antenna; *m,* mandible; *lp,* labial palp; *lig,* ligula; *x,* maxilla.

(3) Bees can both bite, and suck or lick. The mandibles and maxillæ have sharp cutting edges; the mandibles are used in comb-making. The new organ in these insects is formed from the fusion of the free parts of the ligula as seen in the Cockroach; it becomes a long, grooved filament commonly styled the "tongue." Maxillæ, labial palps and ligula, when pressed together, constitute a tube up which the Bee draws nectar. The tip of the ligula is spoon-shaped (Fig. 17).

As pollinators, Bees are grouped as:

(*a*) Short-tongued, with tongues two to three millimetres long. Example, Ground Bees. Mignonette is visited by this type.

(*b*) Medium-tongued, in which tongues are five to six millimetres long. They take home both nectar and pollen. Hive Bees are probably the most intelligent of the insects; it shows in their well-directed efforts to get honey from places difficult of access, and in the way they economise time in a round of visits. Blue and purple are said to be their favourite colours. They visit a great number of flowers, among which are Geranium and Heather. In the list of "pollen-flowers" are Rose, Marsh Marigold, Broom, Gorse. Wasps visit a few flowers; in particular they select Figwort, which has dull-coloured, meaty-smelling flowers.

(*c*) Long-tongued, with tongues ten to twenty millimetres, are typified in the Humble Bees. They are specially suited to Larkspur, Columbine, Foxglove, Snapdragon, Red Clover, etc. There is a saying: "No Humble Bees, no Red Clover." The Garden Pansy is pollinated by Humble Bees and Butterflies. Humble Bees have an added advantage in their weight; it depresses the lower lips and thus opens the throats of some flowers which are closed even to Hive Bees. Humble Bees often bite holes in the nectary ends of flower-tubes (e.g. Columbine); they and others which come after them take the nectar, but do no pollen-distributing.

Whilst some beetles and flies eat pollen where they get it, the Hive and Humble Bees have quite definite arrangements for collecting it and carrying it home to feed larvæ. To begin with, a great part of their bodies is covered with soft feathery hairs which dust off the pollen from the flower as a brush might; if the pollen is even slightly sticky it stays amongst the hairs. The hind-legs are specially modified for the work. The hairs there are more like bristles; one joint is thickly clothed with them. On the same leg is the Bee's "market basket." It is a hollow at the back of one of the joints edged with stiff bristles. A Bee going about its marketing amongst the Gorse blossoms makes you stay to admire the smartness of its performances. It strokes and brushes until it gets itself pretty well dusted over. Then the harder hairs of the hind-legs set to work to scrape the grains from amongst the soft fur. In cases where pollen is powdery, the sucking-tube of the insect moistens it with a little honey. It is kneaded up into little balls and stuffed into the baskets. Very deftly the Bee lifts a leg on one side and clears those on the other of their pollen, then stows it away in the basket, which may get filled to overflowing. Only the worker Bees possess these special contrivances for pollen-gathering.

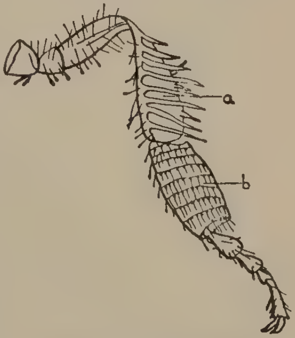

FIG. 18. HIND-LEG OF HONEY BEE

a, fourth joint with pollen basket; *b*, fifth joint with stiff bristles which scrape pollen from the opposite side of the body and transfer it to the basket there.

(4) Butterflies and Moths cannot bite at all; the mandibles have disappeared. There are two labial palps present, but their extraordinary organ is the sucking-tube upon which they depend for food.

Imagine the two typical maxillæ to be drawn out each into a half-tube and that the two halves are fitted together to form a closed tube, open at the free end. This is the origin of the Butterfly's "tongue." Except when using it, the insect carries it coiled up in a spiral on the under-side of the head. Through this "proboscis" (another name for it) it can suck up nectar from the bottom of long floral tubes. By the spines at its tip it can break into plant tissues. Hawk Moths get the honey whilst they are hovering in front of the flowers: they have no need, therefore, of a platform for alighting (e.g. Honeysuckle). The Butterfly's tongue is about the same length as the Humble Bee's, but some British Moths have tongues thirty millimetres long. The Red Campion is a Butterfly flower. Many of the Moths fly only by night, and there is a striking correlation between their extremely long sucking organs and the length of the nectar-tubes in certain flowers which are open only in late dusk. Such flowers are white or pale yellow, and therefore visible at that time. Honeysuckle and the Tobacco plant shed their fragrance after nightfall. The Moths, therefore, do not lack guidance to the flowers. Honeysuckle and the Climbing Convolvulus have flower-tubes so long that only the Hawk-Moth with its inch-long tongue can reach the bottom of them.

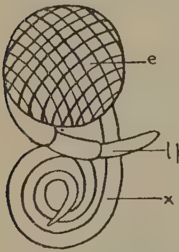

FIG. 19. PROBOSCIS OF LEPIDOPTERA (SIDE VIEW)

e, compound eye; *lp*, labial palp; *x*, proboscis formed from united maxillæ.

GENERAL MARKS OF IDENTIFICATION

Beetles. Two hard wing-cases in front and two soft flying wings behind, folded when not in use.

Flies. Two clear wings, bearing no scales or hairs.

Bees and Wasps. Four transparent wings; bodies usually banded, yellow and black.

Butterflies. Two pairs of scaly wings, folded upwards when at rest: long coiled proboscis; antenna with clubbed apex.

Moths. Two pairs of scaly wings, outspread when resting; long, coiled proboscis; antenna with feathery apex.

Why Insect and Flower Co-operate

The insect wants food; the flower (to speak figuratively) wants pollen from another plant. The flower lays its plans to charm the bee—by its beauty, by its fragrance, by the more substantial bait of its sweet juices. But it requests service in return: it asks its visitor to act as a carrier of the coveted golden dust. Both see that by co-operating they will gain much and lose nothing. It is necessary that the nectar be reserved for the visitors who bring pollen; it must not be wasted on such as come empty-handed. So the flower hides the nectar in such a place that it can be got only by an insect large enough to touch the stamens which it carefully arranges in just those positions which lead to their being touched. An insect comes along with a tongue long enough to reach the honey-pot, rubs against the pollen masses, and goes off to another honey-pot of the same colour and shape. She touches the stigma with her pollen-covered body, and the thing is done. More and more cunning grow the flowers in their contrivances; better adapted and more skilful grows the insect. All this elaboration, one of the most wonderful correlations in evolution, because a plant prefers foreign pollen!

Why should this be so much sought after? An experiment gives a partial answer. Select three conveniently placed plants of the Tall Meadow Buttercup (*R. acris*), and make arrangements for covering up two of them so that no insects can visit the flowers—for example, by means of muslin bags; this must be done before the buds open. *Plant A :* leave this uncovered. *Plant B :* cover this. *Plant C :* cover in the same way. When the flowers open, transfer on a brush, a little pollen from flower to flower of the *B* plant. Seeds will, in all likelihood, be formed in *A*, but none in *B* and *C*. This particular species of plant is *self-sterile*; it can produce no seed unless pollen is brought from another plant. This case, however, is extreme.

As the result of many observations and experiments carried out by hosts of workers we know a great deal about the effect of the fertilisation of one flower with pollen from another, i.e. of *cross-pollination* leading to *cross-fertilisation*. It very generally increases the yield of seed, and that seed produces plants which are superior in every way to those which are due to *self-pollination*.

So the answer leads us back to the great necessity for carrying on the races of the plants.

CHAPTER V

THE LIFE-HISTORY OF THE WILD HYACINTH

Scilla non-scripta

> Sheets of hyacinth
> That seem'd the heav'ns upbreaking through the earth.

THEY make fairy carpets for our English woodlands in the breaking spring. They come to us after the melancholy greyness of winter with exquisite promise; they mingle with the finely shaded green of young grass and the broken shadows from opening leaves. They are the flowers of the children—the Bluebell of the children of England, as the Harebell is the Bluebell of the children of Scotland.

The student is sometimes confused by the different scientific names which have been given by botanists to one plant; the Bluebell has a terrifying list of them—*Scilla nutans*, *S. festalis*, *S. non-scripta*, *Endymion nutans*, *E. non-scripta*. The French call it *Jacinthe des bois*, and the Germans, *Sternhyacinthe*. Gerard, surgeon, botanist and gardener, who lived in the latter half of the sixteenth century, has something to say about them. He calls them *Hiacinthus Anglicus*, because they grow more plentifully in England than the continental form, *H. Belgicus candidus*. He mentions the white form as growing in certain localities in England, including "Warrington in Lancashire." "The root," he says, "is bulbous, full of a slimy glewish juice, which will serve to set feathers upon arrows instead of glue, or paste books with, whereof is made the best starch next unto that made from Wake Robin roots." Dodoens, the Dutch herbalist of the sixteenth century, says that the root, boiled in wine and drunk, is a cure for the venomous bite of the field spider; he probably quoted this from Pliny.

Classical mythology wove many stories round the name of Hyacinth. According to one of them, Hyacinthus, the son of a Spartan king, was unwittingly killed by Apollo, and from the spot where his blood stained the earth there sprang the flower now bearing his name. Again, the arrangement of the veins in the leaf is fancied to indicate the two Greek letters "AI"—an exclamation of woe—the moan of Apollo for the youth he had loved.

The Wallflower and the Broad Bean are foreigners amongst us; man leaves them no peace, hustling them from place to place, tampering with their bodies. But the Bluebell you can visit in the home which it has chosen for itself. And in doing so you should set out with the distinct intention of finding out what binds the plant to that particular home. Is it a matter of preference? Is it a matter of necessity? Is there some factor acting there which is particularly favourable to it? You will have to take stock of its neighbours and their mode of life. You will keep in mind that they must all have food to eat, water to drink, air to breathe, light and warmth; they must have a chance of rearing families and room for new homes for their families. All living things frequenting that spot (and these include animals) are in competition for the wherewithal to meet their needs. Life is a struggle, for the individual and for the race. When you see a piece of ground fully occupied by plants, you are looking at the victors in the fight. They have had the constitutions, the special requirements, the equipment of weapon or lure necessary for them to take and keep possession there. They are living as a settled community. The study of plants as they live in such an association has quite recently come to be regarded as an extremely important branch of botanical investigation. It is named *Ecology*, a term derived from the Greek *oikos*, a dwelling, or, the affairs of a house. Such study must cover every factor which is active within the plant household; it must include: (*a*) the full range of *climatic factors*, chief of which are rainfall and temperature; (*b*) the *edaphic factors*, i.e. the physical and chemical character of the soil; (*c*) the *biotic factors*, the interacting influences of all the living things, plant and animal, operating in the soil and over it. These are bare hints to you with which to make a beginning in this kind of work; in each of the following chapters a little more will be added. Systematic Ecology involves scientific research of great difficulty and great extent, requiring the co-operation of many bands of workers. It becomes national work, for on it must be based every system of scientific agriculture. The botanical student ought to adopt its methods and spirit from the start.

The Bluebell is not too difficult for a first subject. When someone asks what are its *habitats*, you probably name the places where it lives—the woodland, hedgerow, etc. That is one quite correct idea of the term " habitat "; but the botanist of to-day uses it in another way, including in its meaning the whole range of conditions which enable it to live in that place.

Look for the Bluebell in as many kinds of woodland as you can get access to. You do not find it in the deep shade of evergreen Spruce or Fir; you do not find it where the Beeches grow thick and close; you may find it under Oak, or associated with sparse distribution of Beech or Elm. Where the undergrowth is very luxuriant the Bluebell does not make much headway; but it may turn into a lake of vivid blue the more open glade with its young trees standing here and there.

Beyond the edge of the wood in which it has found congenial quarters it may venture out a little way. Such stragglers into grassland show by their poor leaf-form and their meagre flowers that the habitat does not suit them as well as that in which their handsome relatives live in the wood. You may chance upon a Bluebell tragedy; that it is for them when man cuts down their tree companions. Such Bluebells as survive the sudden exposure change their habits; instead of a clump of upright leaves, they may go as far as to flatten themselves out on the ground in limp rosettes.

As you proceed through a wood you may be surprised to find that, whilst the trees remain the same, and the amount of light they allow to pass is not appreciably altered, the Bluebells die out. This means that you will have to seek out another factor which has varied within the area and which must be stronger than the *light* factor. This is a matter for future work.

In early May you will in most localities find the Bluebell at its best, rejoicing in the spring sunshine before the wood and the hedgerow have put on their full dress of foliage. Probably by that time the Primrose, the Wood Anemone and the Lesser Celandine will be fading out of their prime within the same habitats. The Bluebell's tree associates are shading it a little, but not too much, with their young leaves. The young grasses are not strong enough to smother it. This is its one chance of flowering and getting its seeds well ripened.

Observation carried out on these lines will help you to realise one or two principles which are acting amongst plants: (*a*) There is a certain quality and quantity of illumination which is an optimum for each kind of plant; the Bluebell is best suited by semi-shade. (*b*) Throughout the year there may be a seasonal succession of blossom within one habitat. (*c*) Whilst the light factor has been obviously very effective in deciding the distribution of the Bluebell, there must be some other, or others, which are even more powerful. (*d*) It is plain that Ecology is a complicated subject, and much caution must be observed about accepting suggested connections between cause and effect.

The Bluebell Plant in Flower

It is best to start with the plant in this stage.

Compare together a number of the largest specimens you can get. A bunch of leaves in the midst of which is an inflorescence seems to have thrust itself out from the conical top of a whitish bulbous structure. There is no outward trace of a stem, nor of a tap-root; short irregularly arranged roots emerge from the base of the bulb.

The leaves are of a fresh type; so long and narrow that their sides are parallel, veins running parallel with the sides, and no outstanding mid-vein. The average length is about ten inches, and the breadth half an inch. The Broad Bean and the Wallflower possessed the *net-veined* type of venation; the Bluebell has the *parallel* type. This is not an unimportant distinction. Those botanists who have been trying to establish records of the history of plants through their fossils, have found plenty of parallel-veined leaves in the earlier rocks, but none with reticulate venation in rocks older than the Cretaceous. Their incoming marked an epoch in plant evolution. Venation is used now as one character in placing plants in one or other of two great classes (p. 93).

Unless they have decayed, you will find thin membranous sheaths holding together the lower portion of the leaf-cluster; they are really leaves which have stopped short in their development, and are styled *sheathing bracts*. Leaves which arise from an underground part of a plant, as these do, are often spoken of as *radical*, as if they came from a root—which is not correct.

The inflorescence is a raceme from which the "glewish juice" issues plentifully when you crush it. The stalk grows up long and bare until it tops the leaves, and then it puts forth its flowers. They are short-stalked and the whole assemblage of them makes a beautiful mass of colour. Every visible part of the flower is blue, the pedicels are blue, bracts are present and they are blue, even the main axis may have its dull blue tinge—all parts contribute to the general scheme of attraction. I hope you will linger over this to admire what the lens discloses of charming harmonies of green shaded with blue and purple.

You will find no green calyx. The outside whorl consists of three free, petaloid members; the second whorl is almost similar. When there is no difference evident between these two rows, it is customary to include them under the term *perianth*. The general effect of the flower is tubular, for the perianth parts are tightly pressed together, though they are not actually joined. They curl over at the top when the flower is fully open.

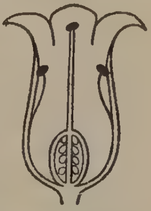

FIG. 20. BLUEBELL (LONGITUDINAL SECTION)

Each of the petaloid leaves has a stamen adherent to it through part of its length. The ovary is pear-shaped, tapers upwards and bulges in six longitudinal ridges: within it are three chambers. Connect the form of placentation with that in the Broad Bean.

The latter has one carpel which, when folded, bears the carpels along its ventral suture edges. The Bluebell's three carpels do the same; their blades merge as the chamber walls and the three placental margins unite as a central column or axis. To this the ovules are attached as before; this type of *placentation* is *axile.* (With this may be compared the *free central* type, as seen in Primrose; in this the ovules are seated on a mound-like placental upgrowth which does not reach to the top of the ovary chamber.) The style tapers up to the three-lobed stigma, which may be flushed with blue. Colour and fragrance lure the Bee to the nectar which oozes from the furrows in the ovary walls, and of which you may find a little glistening at their base. The Bee must push its head as far down the flower-tube as the lower anthers before it can get at the nectar. It may draw out a head yellow with pollen dust; if it goes on to visit a flower in which the stigma is in the receptive condition it may, in pushing past it, leave some of the pollen. Cross-pollination may then occur. The stigma is ripe before all the pollen is shed, thus making self-pollination possible.

An immature inflorescence is short and the flowers crowded. All parts are then green. One service rendered by the bracts is then apparent. They are comparatively prominent, firmer in texture than in the open flower, and they wrap over the buds in such a way that the inflorescence looks rather like a single flower. The inflorescence shows very well the changes in attitude assumed by flowers as they mature. The flower-buds are erect, the fully opened flower droops to one side, the fruit is raised to the erect position again.

The expanded flower is very conveniently placed for insects; the petal lips are useful platforms, and the way in which the flowers line up along one side of the axis provides the shortest flight from one to the other of them. The slight droop of the bell protects the pollen from rain.

The Bluebell makes a good centre round which to do some simple classification of plants. Compare it with Tulip, Daffodil and Crocus. All of them have aerial parts which rise from swollen buried structures, and all of them have parallel-veined leaves, so they suggest relationship.

A. In Bluebell and Tulip, you have a perianth in two whorls of three each, six stamens, three carpels, and a three-celled ovary which is superior.

B. In Daffodil, all these details are the same except that the ovary is inferior. The Daffodil is made more showy by the *corona,* a circular outgrowth from the perianth-tube.

C. Crocus has an inferior ovary. It differs from the other two types in having only three stamens.

In *A*, *B* and *C* we have types of plant Families; names will be given later; find as many examples as you can to place under each head.

Follow the history of the flower on into the fruit. The ovary wall dries and hardens; the fruit is raised to the upright position. When ripe it splits from the top downwards into three valves. The small, hard, brown seeds are shaken out as the wind moves the flower-stalk.

This is a type example of one class of fruit—the *capsule*—which is dry and which opens to distribute its seeds. There are many variations on the type. In the Campions and others of their Family, the capsule splits into twice as many teeth as there are carpels, and the teeth curl back, sometimes closing up again in damp weather. In the Pimpernels and Plantains, a queer little lid detaches itself from the top of the capsule. The Poppy is rather elaborate. Its capsule has many partitions extending from the walls towards the centre, and the seeds are attached all over their surfaces. The top of the capsule resembles a very flat roof with projecting eaves; in the walls, just under the eaves, there open triangular, hinged windows; these flaps of wall open when the air is dry. The Poppy capsule stands erect and the seeds must stay within it until the tossing of the wind flings them widely around. In some Campanulas, similar escape pores are present, but at the base of the capsule; this capsule, however, is pendent, so that the seeds again have to wait for the wind to scatter them. Arrangements to scatter seeds in this way are spoken of as *censer* mechanisms.

For comparison, examine fruits of the Violet. They split into three valves. These dry up still further; the line of tissue down the middle of each valve contracts most and the seeds fly out, as if you had squeezed them out with your finger and thumb. This is a species of *sling* fruit.

Balsam and Wood-sorrel are more fleshy than the fruits mentioned above, even when ripe; but they explode when touched, and the seeds squirt out.

The type of fruit described for the Wallflower is called a *siliqua*; Shepherd's Purse has one essentially the same, but much broader in proportion—a *silicula*. Both of these are forms of capsules.

The History of the Bluebell Bulb

The external appearance of a bulb varies very much—according to its age, for one thing. Examine a series and try to find correspondences between the bulb condition and the condition as regards leaves, flowers and fruit. Some are firm and white. Some have outer wrappings of slimy decaying stuff; some are shrivelled; in both of these the aerial parts are far developed.

Treat your bulbs in three ways: make a longitudinal section and a transverse section, strip off the coatings one by one. On the outside may cling a number of scales; then you arrive at the thin, longer, membranous scale-leaf which holds the foliage-leaves together. Each one of your foliage-leaves continues down into the bulb, and with its flattened and thickened base encircles the younger leaves. All are sticky with sap. The bulb is really made up of these succulent leaf-bases of foliage-leaves; the flower-stalk lies near the centre. All of them can be traced to an origin in a small flattened cone of hard tissue, from which springs also a circlet of roots.

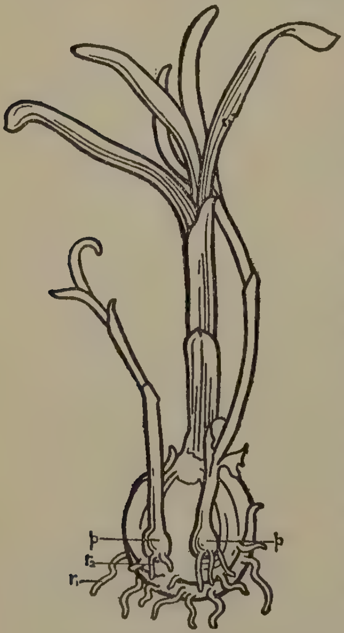

Fig. 21. Bluebell showing Vegetative Reproduction

Condition in May 1927. *p*, *p*, two new plants arising in axils of the leaf-bases of the parent bulb, part of which has been removed to show them; r^1, roots of parent bulb; r^2, roots of young bulbs, growing through the bulb scales.

The small, central, hard area is all the stem the Bluebell possesses. Notice its flattened base, free from roots, which looks as if it had once been attached to something. Notice also, in longitudinal sections, the division of the bulb into an outer part of very soft translucent character (the shrivelling scales), and a firm white cone made up of the bases of foliage-leaves—the flower-stalk embedded in these.

The roots may come off at a level above the lowest scale-leaves and pierce the bases of these. They are short and numerous. They emerge in irregular order, and they arise from a stem, not from an original tap-root. Roots are called *adventitious* when their order of emergence is irregular and when they spring from any other organ than an older root, e.g. from branches or leaves.

Some of your specimens may show two or more small bulbs enclosed in the pulpy outer scales; Fig. 21 is taken from one in which the daughter bulbs are independent, their root systems already active outside the parent.

Compare with the bulbs bearing open flowers, some which are less advanced, in which some buds are still hidden away. The outer casings are still fairly firm and white.

It was chiefly to study this very distinctive plant-form and to learn how it came into existence, as well as to introduce the many important questions relating to it, that this plant's life-history was included in this book. A paper embodying the results of a special study of the Bluebell was published by Dr. W. G. Woodhead[1]; it should be read if possible.

There are two ways of gaining knowledge of the history of the bulb: follow both if you can. (*a*) Pay visits to the habitats of the plant and collect bulbs of all ages; in particular, look out for seedling bulbs in November. (*b*) Make observations from seedlings reared at home or in school. It takes several years for a seedling to develop into a full-grown plant; there is here an opportunity for one class catering for its successors, and also for the establishment by classes of a set of records extending over a longish period.

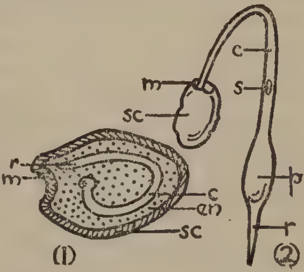

FIG. 22. GERMINATION OF ONION

(1) Onion Seed; (2) Onion Seedling.

sc, seed-coat; *m*, micropyle; *en*, endosperm; *c*, tubular cotyledon; *r*, radicle; *p*, enlarged region of *c* within which is plumule; *s*, place from which first leaf will emerge.

Before investigating the Bluebell seed it may be helpful to take a look at the Onion seed (Fig. 22). It is something entirely new in our seed-studies — nothing in it to remind us of the Bean. Lying in a bed of greyish-white matter is a simple cylindrical body curving under the arch of the seed-coat; the more pointed end lies near the coat. This is the embryo, part of which is tubular. In course of germination, the pointed tip, which is the radicle, lengthens and comes out as usual. In the Bean the next move was due to the lengthening of the stalks of the cotyledons. In the Onion it is the other end of the cylinder which elongates. In the Bean, the two seed-leaves were pressed close together and for a time enfolded the plumule. Imagine that these two leaves were thinned down to paper thickness and that they joined to form a tube. Then growth would have to go on by the extension of this until at last the plumule freed itself from the tube. In the Onion the hollow upper part of the coiled body in the seed is of the nature of a cotyledonary tube, and within it—deep down and exceedingly small—sits the plumule. I am not asking you to believe that the tube was necessarily formed by the union of two cotyledons; as an illustration it may help you, however, to recognise the nature of this new type of seed. As a matter of fact, there appears to be only a single cotyledon present and it never becomes leaf-like. The number of cotyledons is taken as one of the fundamental characters of Flowering Plants. Various botanists have tried to find out whether *Monocotyledons* (plants with one cotyledon) were derived from *Dicotyledons* (plants with two cotyledons) or vice versa, or whether the two have followed two lines of descent from a common ancestor. A theory which many hold to-day is that they had a common ancestor which possessed two cotyledons, and that the Monocotyledons have been derived from these through fusion of the two cotyledons. Another opinion is that one of the two cotyledons of the ancestor has failed to develop in the race which has become the Monocotyledons. It is evident that our small seeds have brought us into big controversies.

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[1] "Notes on the Bluebell." *The Naturalist*, February and March 1904.

There is another great new feature to be explained. The Bean embryo filled the seed-case; it was fed for a long time from what was stored up within its own seed-leaves. The Onion—the Bluebell also—has no seed-leaves which could serve this purpose. On the other hand, their seeds contain something besides the embryo—that is, the substance in which the latter is embedded; this is food-stuff. Such a provision for the embryo, lying *outside itself*, is called *endosperm*. Such a seed is said to be *endospermous* (or *albuminous*, an older term). The Bean is *exalbuminous*. In the course of germination, the radicle of the Onion seed lengthens and grows downwards; the tubular cotyledon lengthens and grows upwards as a narrow arch; the tip of the cotyledon remains, during this time, embedded in the endosperm. The plumular bud, sealed within the enlarged base of the cotyledon, in course of time sends up a tubular leaf which passes out of the tube at a slit (Fig. 22).

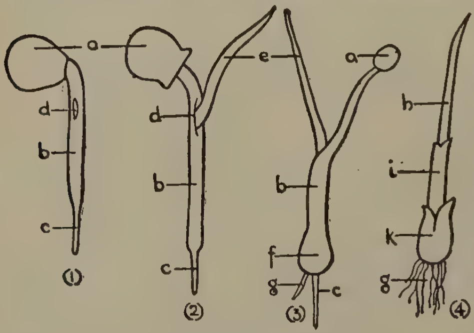

FIG. 23. BLUEBELL SEEDLINGS

a, testa; *b*, cotyledon; *c*, radicle; *d*, slit in *b*; *e*, first foliage leaf; *f*, swelling at base of leaves; *g*, adventitious root; *h*, second year's foliage leaf; *i*, sheathing leaf; *k*, base of first year's foliage leaf.
(3) and (4) are on smaller scale than (1) and (2).

The Bluebell seed is small, hard, black. Its endosperm resembles that of the Onion in a general way. Again there is only one cotyledon, and it behaves in much the same way as that of the Onion.

Follow now the germination of the seed. The radicle emerges. The tubular cotyledon lengthens; its tip never gets free from the seed, which means that the increase in length must push the other end outwards and downwards. The seeds germinate amongst the loose debris on the floor of the wood, and there they find an easy root-run. The young seedling is a queer-looking object—a tapering radicle, continued upwards as a tube in which at one point is a small slit, the tube disappearing into the black seed-case (Fig. 23). Why does the tube tip not come out? Microscope examination (which you may postpone) shows that the tip is solid and is actually a feeding organ. Very gradually it is dissolving and absorbing the endosperm. What it takes it passes on down the tube to be used for its own growth and also for that of the plumule at the bottom of the tube. This is a really wonderful provision for the young plant's start in life.

The plumule of the Bluebell seedling keeps within the tube of the cotyledon until it reaches the slit, through which it pushes out. A single foliage-leaf represents the result of one season's activity; it is full grown in the May following the autumn of germination. This leaf is roughly semicircular in outline, lacking the thin edges of the mature plant's leaf-blade. It may be compared with the Onion leaf, which remains tubular in adult form.

The first sign of divergence from the normal course of development which is shown by a bulbous plant is a thickening of the base of the cotyledon which is evident even before the foliage-leaf is free. The latter in turn swells basally, and before the end of the season the two bases together constitute a tiny bulb. The cotyledon tip maintains connection with the seed even after the foliage-leaf is at work, finally shrivelling in its upper part. At the end of the season the two leaves die off down to the top of the bulbous region, which persists. The first year's bulb thus consists of two scales, the rudimentary stem being a mere disk. Within the first year the original radicle decays, and its functions are transferred to adventitious roots rising from the stem disk.

In ensuing years foliage-leaves flourish and die, always leaving behind them a juicy base as an addition to the bulb. At the beginning of each year the old, outer scales empty and decay. The final product is a mature plant in about five years. Then, on the still squat stem stand not only several of the thick scales, but a group of young foliage-leaves and an apical bud which is a young inflorescence. In the axils of some of the scale-leaves are buds. The whole is a stem with undeveloped internodes, together with the usual appendages of a stem. It is sometimes spoken of as a big bud; more accurately, it consists of one bud united with portions of an older bud. The buds in the axils of the scales repeat the history of the parent terminal bud; each of them assumes the bulb form; they may reach the stage of root-production whilst yet within the scales.

The Bluebell bulb is a traveller within its woodland soil. We know that the seedling bulb begins life on the top of the ground. If we lay bare a section of soil in which plants are doing well, we will find bulbs distributed at all levels down to about eighteen inches. How did they get there? It looks as if two causes were at work. (1) Bulbs more than a year old are often greatly elongated (Fig. 24). Dr. Woodhead suggests that the effect of this elongation (which may be repeated year after year) is to drag the bulb lower down. Try to find evidence of this by making a collection of bulbs of all shapes, collating size and shape with the level at which the bulbs are found. (2) Bluebells are provided with an organ which in some other plants is known to draw them deeper into the ground. After the primary root of the bulb is gone, a long, stout root emerges. It looks normal for a time, then begins to wrinkle transversely in its upper part. This crumpling is due to a distortion of the root-tissues, which contract lengthwise and bulge sidewise. The root is compelled to shorten. As its lower end is fixed by the root-hairs, the upper end must move. In doing so, it of course takes the bulb with it. Such a root completes its existence within a few months and then dies off. Next year the story is repeated, and the next again. There may be several such roots on one bulb. They are known as *contractile roots*.

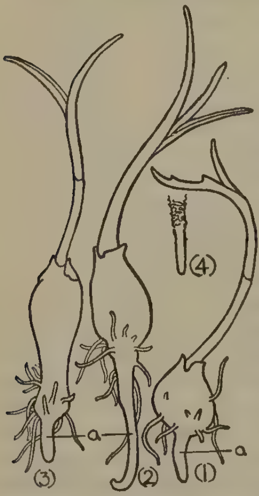

FIG. 24. BLUEBELL PLANTS IN MAY

(1), (2) and (3) show successive stages in elongation of bulbs; the contractile root, *a*, is in its early condition; (4) Root *a* from an older plant, after contraction.

The Tulip bulb may be compared with that of the Bluebell. By following the history of a Tulip bulb throughout the year, it will be disclosed that its fleshy concentric members are complete leaves, not merely the bases of dead-and-gone leaves. It, too, forms new bulbs from buds subtended by the bulb-scales. They may be established at the depth most suitable for them in a strange way, which is not, however, very common. Directly the new bulb works its way through the scale it begins to extend downwards, giving rise to a tubular body within the base of which is the leafy bud of a new bulb. Such a contrivance is a *dropper*.

The bulbs which have been described are styled *tunicated bulbs*, indicating that each scale is a complete wrapping. In such as the Lily bulb the scale-leaves only partially encircle the core; they overlap like the tiles on a roof. They are *scaly bulbs*.

The subterranean part of a Crocus plant in its winter resting state is not to be mistaken for a bulb; it is a *corm*. Strip one of its coverings, and make sections of others (Fig. 25). You will find everything prepared for next spring. Instead of the stem being excessively reduced, it is the stem which forms the hard-grained mass of the structure; it is surrounded by the membranous remains of old leaves, the bases of which extend right round the corm. In their axils are buds, the initials of the new corms of the year to come. Attached to the base of the corm there may be some fragments of the corm from which it grew. The crown of the corm ends in the bud of a flowering axis; the stem-growth is carried forward by this, which is an old lateral bud. Corms should be examined at various seasons. Long before they come out of the ground the sheaf of leaves and flowers shows all its parts clearly; they are packed up in a transparent membrane which shields them as they pass through the soil. New corms as they form tend to get nearer and nearer to the surface; contractile roots induce them to descend as in the case of the bulbs. *Montbretia*, a cultivated garden plant, may display a chain of corms, for the old ones do not die off readily; here again the specialised drag-root comes into action to keep them at the right depth.

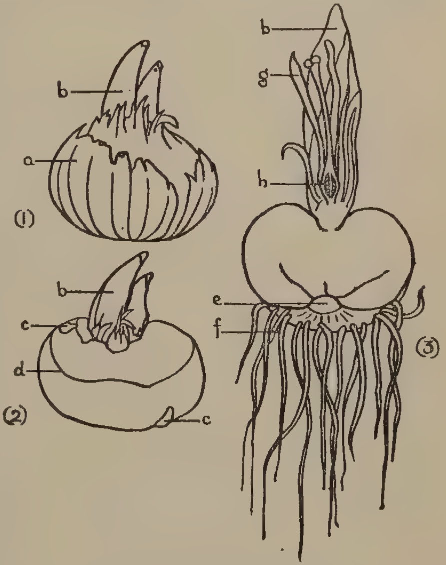

FIG. 25. CROCUS CORM

(1) Corm, external scales present; (2) Corm, scales removed; (3) Section of more advanced corm. *a*, scale leaf; *b*, sheath covering young shoot; *c*, axillary bud; *d*, circular leaf-scar; *e*, point of attachment to older corm; *f*, adventitious roots; *g*, foliage leaf; *h*, ovary of flower-bud.

Bulbs and corms are excellent examples of plants which have two methods of propagation. First, they set seeds in the ordinary way. Second, a bud from the parent—a bud-corm or a bud-bulb—detaches itself and sets up independently. The second process is called *vegetative reproduction* or *multiplication* or *propagation.*

Apply chemical tests to some of the bulbs and corms. Iodine shows the Crocus corm to consist mainly of starch, but shows that there is little or none in the bulb-scales of Onion and Bluebell. Test these for sugar with Fehling's solution (p. 311). The Onion contains much sugar, the others do not. There is a third substance of similar character which may be present, *inulin.* If slices of material are left for a time in alcohol, any inulin present will crystallise out as shining specks adherent to the cell walls; these crystals will dissolve in water. The presence of the inulin is discernible only under the microscope. This test shows that inulin abounds in solution in the sap of the Bluebell bulb, but not in Crocus or Onion.

Starch formed the mass of the Bean seed, as we saw, and its fate was to become food for the embryo: the bean was a granary. So are bulbs and corms. And the reason for some plants requiring a special granary? One point to be noted is that they are spring plants which get growth and seed-production completed during weeks when heat and light are none too favourable, and which do it with great rapidity. That is made possible because they have these great reserves of food to draw upon—the starch, sugar or inulin in their *storage organs,* to use the common term.

Note another point—the granaries are buried. As they seem to prefer earth to air, such plants are named *geophytes* (Greek *ge,* the earth; *phyton,* a plant). The soil is their winter home, or *hibernation* quarters. Perhaps an explanation of these departures from plant customs is to be found in those parts of the world where subterranean storage organs are the rule in vegetation instead of the exception. Such are the High Alpine regions forming one type, and the desert, the semi-desert or the Mediterranean habitats forming another. The characters common to all are (*a*) the extreme brevity of the season into which plants have to crowd their active life, and (*b*) the rigour, due to cold or heat, of the rest of the year. In which connection we may remember that our Lilies come from Asia Minor, our Tulips from Siberia, and our Narcissi from Southern Europe. The chief characteristic of the Mediterranean type of climate is that the rains fall in winter and early spring, and the rest of the year is nearly rainless. If a plant is to survive it must be able to endure severe drought, and must act swiftly during the short spring period of warmth and moisture. On the high mountains and in the land of Polar cold, there may be only a few weeks in each year which can be utilised. In both types of habitat plants must be ready. So several habits have evolved. During the short active season the plant forms excess of material (starch, sugar, etc.) which it transfers to some store place such as a bulb. It devotes less to the formation of seeds, which take a long time to form and ripen, and which run risk of destruction before getting below ground. The big storage organs are safely housed in the ground from the first, and during the long period when life above ground would be impossible there may be quiet changes going on in the bulbs, which lie safe from the dangers of wind, frost or desiccating sunshine. Next year's buds are being elaborated, and by the time the next growing season arrives, leaves and flowers are planned out in every detail, waiting only for the right amounts of warmth and moisture to shoot up and take advantage of every minute of the new year. Some of the buds are detachable and capable of separate existence, so the generations are carried forward even if seeds are a failure.

Bulbs and corms are only two forms of storage organs; others will come under notice later.

The habits outlined enable bulbous plants to succeed in the competition for light in certain habitats in this country. They give a plant a favourable place in the *seasonal sequence* of plants. The Bluebell, for example, abounds in the woodland. This is possible because its stored food enables it to come up in very early spring and get even its flowering and fruiting accomplished before the place is deeply overshadowed by tree foliage. You will find that many of our spring flowers have subterranean storage arrangements.

Bulb Culture

Cultivating a selection of bulbs (Garden Hyacinth, Tulip, Narcissus, etc.) for home decoration in winter and spring will be instructive because of the quick response shown to varied treatment. Some rules of culture are general; some have to be modified for individual plants. Bulbs can be massed closely because they depend so little on soil. Crocuses and Daffodils may be left undisturbed in the same spot for years, provided that the ground is fairly dry in the summer season. If grown in pots, bulbs should be given soil which is a mixture of turfy loam, leaf-mould and sharp sand. They should not be deeply covered. The first part of the period of cultivation should be spent in a place which is cool and dark; they should be given no water unless they are in danger of becoming absolutely dry. This treatment gives time for the formation of a good root system. Before the flower-spikes show, the bulbs should be brought into subdued light and gentle heat, and given water. Gradually, as good green colour strengthens, flowering can be forced by heat and copious watering. Progress can be controlled very markedly by conditions of varying heat and moisture. Hyacinths can be grown in glasses without any soil, and only pure water need be used; this proves the sufficiency of the food in the bulb. Promote root-growth by keeping them in the dark at first; afterwards, for the leaves and flowers, good light, steady temperature and frequent renewal of the water into which the roots dip (water should not touch the bulbs).

The Bluebell as a Competitor

The Wild Hyacinth keeps its place in a community of plants by mutual adjustments with the other members of it. In ecological language, an *open* plant community is one in which the ground is not fully occupied by vegetation; it is a partially colonised country; there is room for more settlers. The open community may develop into a *closed* community, where every resource is utilised, where there is a balanced adjustment of the necessities of life, and where every individual is watchful, as it were, that it lose nothing to a neighbour, but, if possible, get a little more. The conditions are very complex. Most in evidence is the infinity of arrangements seen above ground designed to get light, heat and air, and to ripen and distribute seeds. In the ground, meanwhile, the roots are hunting for water and all it contains, as well as for air again. In a stable plant community there often prevails a kind of portioning out of the soil strata which partially eliminates competition. The root systems of plants receive great attention from botanists nowadays, and grouping of plants according to the depth of rooting is put to practical use.

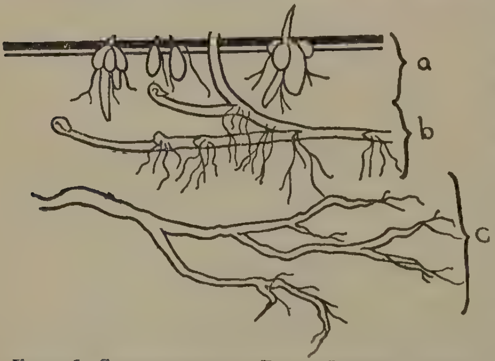

Fig. 26. Complementary Plant-Society: Woodland (Diagrammatic)

a, zone in which Lesser Celandine roots; *b*, zone of Dog's Mercury; *c*, zone of rootlets of tree.

Dr. Woodhead, one of the special workers in this field, describes a Bluebell area in an Oak wood near Huddersfield. He shows how, of three plant species living together, each restricts its active roots to a soil layer of its own. He calls it a *complementary society*.

Within the few inches of leaf-mould at the top lie the roots of the Soft Grass (*Holcus mollis*), which is fresh and green from November onwards through the winter. Below this is dark humus soil, with rhizomes (p. 161) of Bracken, and, temporarily, Bluebell bulbs on their downward journey. The lowest layers of firm, yellowish loam are the feeding ground of the Bluebells. Their active aerial period succeeds that of the Grass, and is succeeded in turn by that of the Bracken, which spreads its fronds just as the Bluebell's seeds are shed. So in that settlement there is a minimising of the conflict within the soil, and also within the sequence of the seasons (cf. Fig. 26).

How the agriculturist has put to use a knowledge of root habits is illustrated in the western grasslands of the United States. The natural grasslands there are of two decided types—those composed of short-rooted grasses and their associates, and those which are long-rooted. Their distribution is determined by the depth at which the water-supplies are conserved. The farmer, aided by the scientist, uses this natural vegetation as an index or guide for the extensions of his cultivation areas.

SIMPLE EXERCISES IN ECOLOGY: THE LIGHT FACTOR

(1) Make a general comparison of the vegetative growth on both sides of a hedge separating two pasture-fields. Does the direction in which the hedge runs have any effect?

(2) What changes of a general character do you recognise within woods—as between the fully shaded parts, the clearings and the margins?

(3) Examine the vegetation which is shaded by a tree in an open park; is it very different from what grows just beyond the shade? Does it vary with the kind of tree?

(4) Transplant Bluebells from a shady to a sunny habitat. Transplant others from the same place to another shady habitat. Compare the results.

(5) What do you find growing round the entrance to a cave?

CHAPTER VI

THE LIFE-HISTORY OF THE LESSER CELANDINE

Ranunculus Ficaria (Linn.)

This is a golden beauty, and most daring. It compels even the suns of March to transform its beds into pools of brilliance.

This plant and the way it lives are so full of provoking difficulties that a whole line of botanists have given it their special attention. It still keeps most of its mysteries to itself. This and the following chapters will introduce you to some of them, and possibly arouse in you the desire to fathom them.

So like a Buttercup that it is popularly taken to be one, it has had many names given to it—scientific and non-scientific. At present it appears in the catalogues as *Ranunculus Ficaria* (Linn.). Note that the word within brackets after the name indicates that this name was given by Linnæus. It has also been known as *Ficaria ranunculoides* (Mönch), and recently as *Ficaria verna*. The French scientists called it *La Ficaire*. *Ranunculus* (diminutive of *rana*, a frog) has been chosen for it because this plant and some of its relations are frequently in bloom in moist places at the time when young frogs are lively there. *Ficaria* (*ficus*, a fig) was suggested by the shape of the tuberous roots.

In this plant is illustrated very well the multiplicity of folk-names (i.e. names given by the people) which our common wild plants possess. Very often a name is confined to a district. To its yellow loveliness it owes names like Golden Cup, Gilty Cup, Golden Guineas, Goldy Knob; whilst in common with other yellow flowers it is sometimes called Paigle. In Devon one of its names is Kingcup. In the English Midlands there was an idea that the smell of the plant induced madness, and it was called "Crazy." The name Foalfoot refers to the shape of the leaves, and Pilewort to the shape of the tubers. Its Celtic name, *Grian* (the sun), you may think the most poetic.

In early times the Lesser Celandine was, or at least appears to have been, confused with the Greater Celandine, *Chelidonium majus*; both were spoken of as the Swallow-wort, and it is not always clear which is being referred to in some of the older writings. *Chelidon* and *Hirundo* (a swallow) are connected with ideas which were current in the time of Aristotle, and which were quoted by sixteenth-century writers. Thus Pliny says: "The brute animals have also been the discoverers of certain plants; among them we will name *Chelidonia* first of all. It is by the aid of this plant that the swallow restores the sight of the young birds in the nest, and even, as some people will have it, when the eyes have been plucked out." In his list of such plants Pliny includes the Greater Celandine, and he may have intended the healing of the birds' eyes to be effected by this plant only. Another connection was seen by these ancients between the migratory movements of the birds and the coming and the disappearance of the plants. This coincidence in time is several times questioned by the sixteenth-century writers. Dodoens accepts the "swallow" name of the Greater Celandine as being based on the myth of the eye-cure, and that of the Lesser Celandine as referring to bird migration.

The physicians of the Middle Ages traced many more or less fanciful resemblances between parts of certain plants on the one hand, and symptoms of diseases and parts of animals' bodies on the other hand. In their opinion, wherever such a resemblance could be found, it was a sign or "signature" that medical applications of the plant would cure diseases of the organ in question; such was the widely accepted *Doctrine of Signatures*, which was the basis of much of the medical practice of the day. In the Lesser Celandine the pile-like or scrofula-like swollen roots were reckoned to have healing properties when applied to hæmorrhoids and tumours.

Dodoens speaks of the roots as being "full of small threads or hairy laces, with divers knots in them like to wheat or barley corns." He says the two Celandines are hot and dry in the third degree, and the small Celandine is the hotter. "The root, chewed in the mouth, taketh away toothache." Parkinson (1640) recommends it as a cure for king's evil and other tumours. Gerard quotes the opinion of some who thought that even carrying the herb about with them would ease the pain of the disease they suffered from. Pliny says that the juice from the flowers, mixed with Attic honey and heated over a brazier, "scatters the cloudy films that dim the eyesight."

The Habitats of the Celandine

The following are a few selected from a great many which were examined. Let us see what general conclusions we dare draw from them. Before passing on to them, a preliminary word may be said about two puzzling forms of the plant which appear constantly. First, there is the more normal type which produces flowers and sets seeds in ordinary quantities: we will call it the "fertile" type. Second, there is a type in which flowers are very few and seeds rare, whilst propagation from season to season is carried on by tuberous bodies which are situated in the axils of all the leaves; this we will call the "sterile" type.

Habitats. (1) This was near the pathway in a young plantation of Spruce and Larch; the plants sometimes came up through Moss, sometimes through the inch-thick carpet of Pine needles. Light was medium, plants were strong. This is a very unusual place in which to find the plant. (2) On the north-facing steep slope of a narrow valley, full-grown Birch- and Elm-trees stood close together, and the summer shade was deep. Only Celandine and a little Grass grew there; decaying plant matter was cleared from the ground by rainwash. The Celandines were small and mostly of the sterile form. (3) This was the opposite side of the valley in (2), where the tree-growth was young and the trees were scattered. The ground was lightly shaded in summer and open in winter and spring. The soil was glacial clay mixed with much humus, and retained moisture well under its sheet of dead and living plants. Celandine was the predominant ground plant; its splendid array of blossom and its luxuriant foliage showed that it had found an ideal home. Amongst the other plants which in the course of the year played their parts here were trailing Ivy, Red Campion, Dog's Mercury, Wild Hyacinth, Wild Garlic and Wood Anemone. (4) Heaps of Hawthorn branches had been thrown together at the edge of a wood; long Grass grew up through them, and dead leaves had drifted in and stuck. Celandine contrived to keep pace for a time with even the Grass, being drawn out into inordinately long leaf- and flower-stalks. (5) Growth in ditches varies. In one, Celandine may compete successfully with coarse Grass, Nettles and Brambles, its stems, leaves and flowers being extraordinarily handsome. In another, the sterile Celandine may be in solitary occupation of a sloppy soil of black leaf-mould. (6) A little flat of alluvium often flooded by a stream bore no plants besides *R. Ficaria*. (7) Celandine is a striking unit in the spring vegetation on the limestones of the southern fringe of the North Yorkshire moors. (8) It grows well on the Millstone Grit soils of Derbyshire. (9) It is a member of many grass-field associations, and there its life is not too easy. An open field may be one of the driest, most brightly illuminated habitats, and one in which competition is at its height. There, at no season of the year has Celandine much advantage over its companions, and as its roots occupy the same layers as the short-rooted Grasses and other plants present, its difficulties are not small. In such a situation, Celandine assumes a short compact habit of growth both above ground and below. Its associates in one field were Grass, Earth-nut, Narrow-leaved Plantain, Field Rush and a small Moss. How close was the packing may be gathered from the fact that, in a bit of turf about three inches square, there were specimens of every one of these plants together with four Celandines. Here is another example from a grass sod two inches square; in May it was supporting sixty-one Celandine plants; fifty-three were new plants of the season, four were a year or two old, and four were old parent stock. In the fields, it is interesting to see how Celandine spreads most widely in slight hollows such as furrows.

In surveying the situations favoured by Celandine, it must be remembered that it is the few inches of top soil which affect it. These may differ in character greatly from the underlying rock; drainage carries much mineral matter downwards, e.g. lime. Where there is much decaying vegetation on the surface, the top soil will be rich in humus and will retain moisture well.

R. Ficaria seems indifferent as to whether it grows over shales, sandstones, limestones or glacial clay—always provided that the humus content is high and that it is frequently renewed. This last seems to be the deciding factor. The plant manages to exist on ground where humus is scanty, and even in stagnant water, but it does not flourish there. Amongst the least favourable situations are bare clay banks, and sandy or very friable soils.

The Tuberous Structures

Whilst the plants are in bloom, in April and May, mark off as many habitats as you have access to.

In July, August and September visit them; you will find no trace of plants above the ground. July seems to be a "resting" month; after that, if you dig up plants, you will find that activity has begun. In November, when most of our vegetation is dormant, this extraordinary plant sends its first green blades into the frosty air. In December, leaves enjoying a little shelter are well advanced; in January, flower-buds are in evidence; in February, growth is tall, a few flowers are open, and seedlings are to be found. There is great progress in March; April is the month of full blossom; May is the month of ripening of all parts of the plant; June is the month of decay and disappearance. Such is a brief résumé for the year.

What is an August plant like? A more or less globular bunch of hard, white bodies, shaped often like miniature pears—suggestive, too, sometimes, of doll's potatoes. Cut through the bunch. The tuber-like bodies are all attached to a rather irregular mass, from which they break away readily. When sectioned for the microscope, this turns out to have the structure of a stem, and its previous year's history would prove that it is one. The "pears" have the internal structure which characterises a root (p. 187); you will find that they are roots modified to do special work. Hidden amongst the tubers, on the lower end of the stem, is a scar which marks the place where it had been joined to an older underground stem. At the upper end, another scar tells where last year's foliage-stem rose; there may be one or two buds near this.

Test the firm, white substance of the tubers; you will find it to be starch. This is another instance of a plant providing substantially a year beforehand for an early start. The history of the plant can be followed closely by bringing in specimens and keeping them in pots or in garden plots.

The growth of the old stem may be continued by one of the buds mentioned above; every one of the tubers may break away and set up independently. There are many complications, many modes of variation which cannot be detailed here, but which it will repay a keen student to seek out.

The tuberous bodies vary in shape from cylindrical to globular; all are cylindrical when they are young. They seem to be shorter and thicker when they grow in clay soil or amongst matted grass roots. They bear the usual root-hairs, except at the extreme, conical tip. A great many of them possess a minute bud situated near their point of origin from the stem; some have more than one bud. The first-formed tuber of the year's bunch always differs from the rest; it is longer—may be very much longer, one four inches long has been found—and cylindrical or nearly so; its root-hairs are very evidently functional and soil sticks fast to them, which is not true of the other tubers; it never bears a bud.

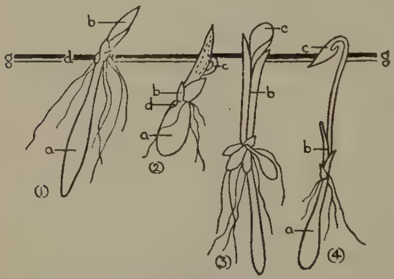

FIG. 27. LESSER CELANDINE: LEAF EMERGENCE

(1) "Spear" bud; (2) Leaf assuming bend as it withdraws from scale; (3) Leaf which has opened out as it left the soil; (4) Leaf emerging as arch.

a, tuber; *b*, scale; *c*, first leaf; *d*, scar of attachment to older plant; *g*——*g*, ground level.

The following is an outline of the course of development of a tuber which has broken away from the stem. The bud near the scar, a tiny dome-shaped swelling, thrusts aside the scale which covers it. As it lengthens, other scales emerge and wrap round the roll of the first leaf. The whole forms a fine-pointed, piercing instrument. Watch the emergence of these dainty "spears." Sometimes the roll opens a little before the point leaves the ground; then you look down into a little green funnel. The way in which a leaf wedges open the sheath may often be seen. Notice also the ingenious way in which the leaf is packed up—that is, its *vernation*. The leaves stand erect within their tube of scales, the blade in line with the petiole; the peculiar style in which they are rolled you should examine closely. At the stage when one foliage-leaf has come out, the next is enclosed in a tube formed partly by its hollow petiole. Watch the mode of exit. Pushing up vigorously, its tip is caught within this petiolar tube and cannot grow up through it. The upper part of the new leaf's petiole grows outwards in a curve, and breaks through the slit part of the older petiole. The result is that when the leaf gets free it looks as if it had lain doubled back within its scale-case—which it certainly had not. This is one way in which the "arch" of emerging leaves may originate (Fig. 27).

A bud which has to bore its way through soil or worm its way through matted vegetation is usually provided with some special adaptation which minimises the risk of injury to its most susceptible tissues. Two common forms of this protective character are exemplified in *R. Ficaria*. The first is the "spear-shoot," in which, as we have seen, the soft leaf-blade is rolled upright and sheathed in smooth scales. The second is the "arch," in which the working point in the operation is the comparatively resistant bend in the petiole, which brings the leaf-tip down alongside the petiole. It is only after it is quite free from the soil that the petiole straightens out, the leaf rises and then spreads out horizontally.

Many very interesting modifications may be found amongst seedlings and amongst perennial plants leaving the ground in spring-time, and may be compared with these two in Celandine. Iris, for example, sends up its slim young leaves doubled lengthwise, clasping each other; they cut their way out like swords.

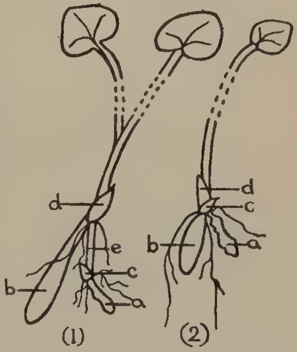

FIG. 28. LESSER CELANDINE: YOUNG PLANTS

(1) Plant with visible internode; (2) Plant with suppressed internode.

a, old, shrivelled tuber; *b*, new, firm tuber; *c*, scale belonging to bud on *a*; *d*, scale belonging to bud on *b*; *e*, internode between *a* and *b*.

Fig. 28 (1) shows a young plant. *a* is the tuber which has sprouted in the current year. Its bud has carried its leaves up on the top of an internode *e*, which remains underground. This was done at the expense of the starch store in *a*, but with the assistance of the absorptive roots of *a*, which appeared directly the bud became active. The leaves got to work, and the node at *d* thickened; from it grew out a second set of adventitious roots and also a new tuber *b*. This filled with starch manufactured as sugar in the leaves and sent down to the tuber-granary. Other tubers may be added in the course of a season. Note the peculiarities of the first-formed tuber, which shares the absorptive work of the slender normal roots. As the new tubers fill, the old one shrivels up. At the end of the season everything dies off except the new node at *d* and the tuber or tubers attached to it.

In Fig. 28 (2) there seems to be no internode between *a* and *b*. This leads us to the fact that there are in Celandine two distinct forms of stem—one with an internode in this position, the other apparently without it. No adequate explanation of the double form has yet been found. The absence of an internode, however, is only seeming: there does exist, as is seen in sections, an undeveloped length of stem.

The older plants pursue essentially the same course, up to a point, as the simple young one which has just been described. In Fig. 29 (2), from the stem bearing a cluster of old tubers *b* rose, as a bud, the new stem *c*, at the first node of which the second set of tubers *e* arose. The aerial axis was continued above this node. Fig. 29 (1) is a full-grown plant in which the internode between the old tubers *a* and the new tubers did not show.

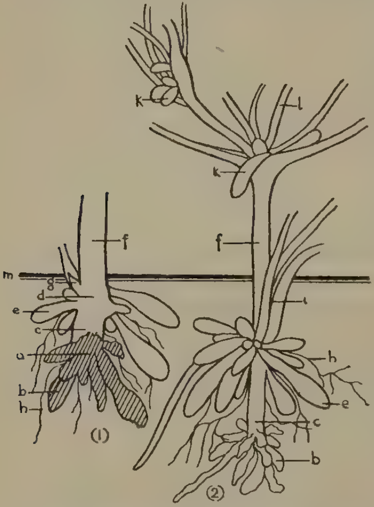

Fig. 29. Lesser Celandine: Adult Plants

(1) Section showing much abbreviated ground internode; (2) Sterile plant with long ground internode.

a, old, rotten stem; *b*, old, rotten tuberous roots; *c*, ground internode between *a* and *d*—only a "neck" in (1); *d*, solid new stem; *e*, new tuberous roots; *f*, hollow aerial stem; *g*, bud enclosed in leaf-base; *h*, root; *i*, first cluster of leaves; *k*, aerial tubers; *l*, cluster of leaves at first aerial node; *m*——*m*, ground level.

The relationship between the thick node of buried stem, the tuberous roots, and the buds seated on the latter has been much discussed. Some observers say that the tubers are adventitious structures *really* growing directly from the stem-node as they *appear* to do, and that *from them* originates the bud. Others maintain that it is the bud which is the direct offspring of the stem, and that subsequently the bud—whilst still microscopic or nearly so—initiates the tuberous root, the latter soon far surpassing it in bulk. A very nice little problem!

One of the most remarkable facts about *R. Ficaria* is that it exists in two forms, the histories of which differ radically—the "fertile" and the "sterile" types (p. 77). Both forms multiply by means of the subterranean tubers, but the sterile plants go farther. Fig. 29 (2) is one of them. In the axil of every leaf of such a plant tubers arise, differing in no respect from those below the ground. These aerial tubers are scattered on the ground when the plant dies down. They sprout freely, and the tuberlings resemble those from ground-tubers.

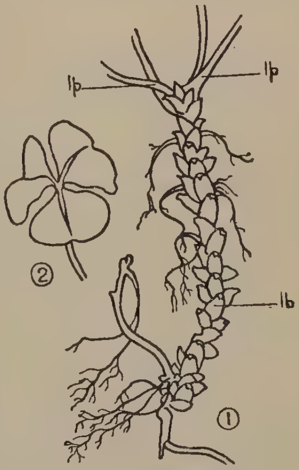

FIG. 30. WOOD-SORREL

(1) Stem covered with old leaf-bases; (2) leaf.
lb, old leaf-base; *lp*, base of leaf of current year.

Tuberous bodies are generally either thickened roots or thickened stems. The tubers of the Dahlia, like those of Lesser Celandine, are roots.

A **tuber,** strictly so called, is the extremity of a shoot which has been arrested in length but has increased in girth. The best known is the *potato.* Examine potato plants as they grow; they possess underground branches (rhizomes). Some branches grow only a little way and then begin to thicken at the end; this is the beginning of a potato. When it is immature, the rudiments of the arrested leaves and their axillary buds, crowded on the dwarf shoot, can easily be identified. They are what are called the " eyes " of a mature potato. The material for the filling out of the tuber has been manufactured by the green leaves and sent down for storage. When the gardener sets potatoes he frequently cuts them into sections first; he takes care that in each section there is at least one " eye." This "eye" bud begins to sprout and gives rise to a rhizomic branch, the beginning of a new potato. The Jerusalem Artichoke has essentially the same history as the potato; it is of more irregular shape.

Amongst the spring flowers which keep company in the woods with the Celandine are others which have made provision for an early start in the season. In the Wood Anemone, the underground stems are thickened and packed with food. In the frail little Moschatel, the next year's store is put away in swollen scale-leaves. As in the Celandine, all the aerial parts of this plant die down when flowering is over; the resting plant consists of the buried stem and these thick leaves. Wood Sorrel looks somewhat similar, but the rows of scaly structures on its creeping stem are the bases of the previous year's leaves (Fig. 30). In the woods, too, we find the bulbs of the Bluebell and the Broad-leaved Garlic.

The Branching

The branching aerial stem and the leaves of Celandine are favourable for studying modifications of form traceable to environment. Sometimes the exact and direct causes are obvious, sometimes not. As long as young leaves remain under mats of old herbage, etc., they remain a pure pale yellow; that is, they are *etiolated* or devoid of chlorophyll (p. 97). They are also small in the blade and thin in the stalk. Older plants which have to fight a way up through grass, brambles, etc., grow straggling and lanky. For a time they, too, are somewhat etiolated, but, in the end, rooted in soil kept moist by the tall vegetation over it, and borrowing support from that vegetation, they may flourish very finely, their leaves being big and glossy, their flowers large and their seeds good. Very likely seedlings will be numerous in the darkened shelters underneath. (See "Habitats.") In very strong contrast with these plants are those which grow in pasture-fields; they are small, compact, and tend to form rosettes.

The branch system looks simple; it is axillary, as usual. It looks as if two leaves arise at each node. Some botanists consider that this is deceptive, that the *phyllotaxis* (arrangement of leaves on the stem) is alternate, not opposite, and that internodes are suppressed. Search for evidence for and against this theory.

The Leaves

Many plants possess two forms of leaf, those lying near the ground having one shape, and those at higher levels having another. Lesser Celandine illustrates variability in leaf-form very well (Fig. 31).

(*a*) The leaves at the main nodes are heart-shaped; their margins vary. Usually they are of uniform dark green; but in some plants a row of greyish-green areas is regularly disposed round the edge. This is an example of a variegated leaf; the appearance may be due to several causes which might be investigated later. Venation is typically net-veined. From the main central vein as it leaves the petiole two side veins branch off, one to each basal lobe; from each of these in turn a single vein (or in some cases two veins) runs obliquely into the side lobes. Smaller and smaller developments of these spread as a fine network over the whole surface.

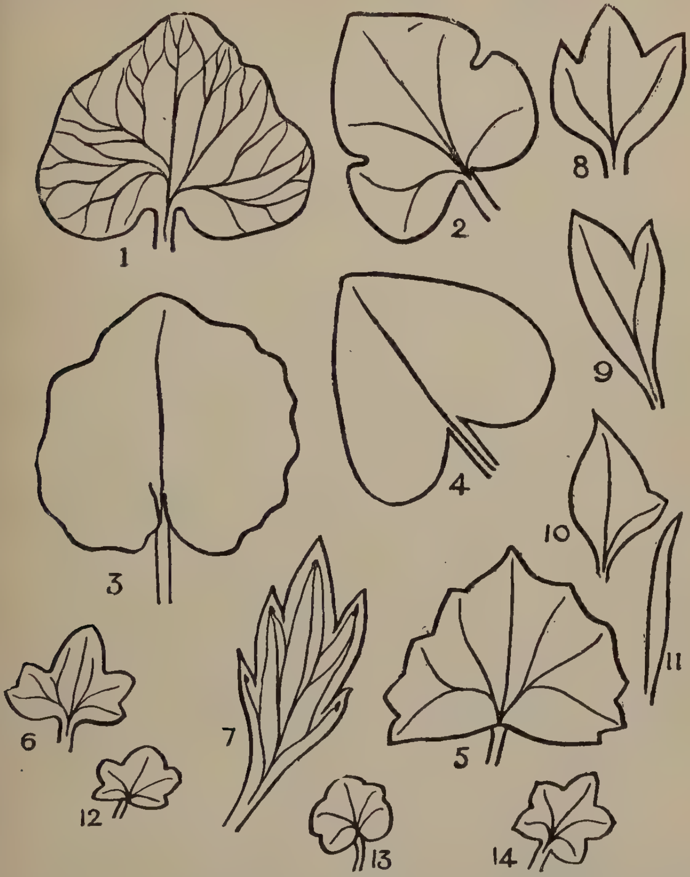

FIG. 31. LESSER CELANDINE: VARIATION IN LEAVES

(1), (2), (3), (4) normal leaves from fertile plants; (5) from sterile plant; (6), (7) from peduncles; (8), (9), (10), (11) from arrested buds in leaf-axils of sterile plants; (12) from tuber-bud unfolding in leaf-axil of sterile plant; (13) first leaf of tuberling; (14) first leaf of seedling. (1) shows normal venation and (7) abnormal.

The apices of the marginal teeth or lobes where a main vein ends, and where usually it is joined by subsidiary veins, are slightly swollen. The internal tissues are peculiar here, and the open ends of the veins allow their fluid contents to escape. These are points on a leaf where surplus water can be driven out easily; their working will be explained on page 261.

(*b*) There is a fairly constant difference between the mature leaves of the fertile plants and those of the sterile plants. In the former, the basal lobes project backwards very far (cordate type); in the latter, the angle between them is much wider and their bases may lie nearly in a straight line, when the leaf outline approaches the triangular shape. The margins of the sterile plant's leaves are generally more sharply cut up.

(*c*) The leaves on the peduncles are irregular in their occurrence. They are small and fine; the outline is triangular; the edges are deeply and sharply toothed.

(*d*) Little clusters of leaves keep company with the tubers in the leaf-axils of sterile plants. It looks as if there were two origins to which they could be traced. Some belong to an axillary branch whose growth has been arrested; they are ill-formed and many-formed. Others seem to belong to the tubers themselves, to be the premature developments of the ever-present "buds"; they are nicely symmetrical, five- or six-lobed; they match the first leaves on a young plant which has arisen from a tuber.

First leaves of tuberlings remain small, and are commonly five-lobed; they are rarely unbroken in line. The leaves of adult plants resemble them when they are young; the lobing disappears as they grow older.

The first leaf of a seedling is very like that of a tuberling. The enlargement of lobe-tips is very marked.

The *scale-leaves* which figure in early stages are the equivalents of the bases of leaves.

THE FLOWERS

The flowers look as if they were terminal in position on the main axis and on the side branches. The pedicels may bear small bracteoles.

The flowers of burnished gold and warm-toned green make a Celandine bank at noon on a sunny spring day a wonderful spot of colour. Every flower is a glossy golden star. Gather them and linger to look at the delicate colour harmonies; above, the petals of yellow with greenish bases against which lies the broken orange of many stamens; below, transparent green shades the gold, and touches of red or brown may give it depth.

The flower is simple in its form as in its colouring; shallow, open, saucer-like, as the more primitive flowers may have been. It is actinomorphic and hypogynous.

The calyx. In many Buttercups, which are related to Celandine, the sepals are very variable in number. In Celandine they are usually three, but occasionally four, five or six. This instability in number may have an historical meaning (p. 86). The sepals are free, and green but for the colourless edges which overlapped in the bud. Their most puzzling feature is the pouched and wrinkled prolongation at the base. Within it is an empty chamber.

The *corolla*, when outspread, is a nearly level platform. The number of petals varies; the commonest number is eight; there may be as few as four, or as many as fourteen. No matter how many of them there are, three of them form a definite outer whorl, alternate with the sepals; these three are longer, broader and finer-coloured than the others. It is possible that there is much meaning in this regularity of number and position in three of the sepals and petals, as well as in the variability of the others. The petals are oval in shape, and free. The outer two-thirds of each petal is highly glazed; the remaining parts combine to form a dull yellow disk, over which lie the stamens in the open flower. The glaze is not affected by water and cannot be rubbed off.

The corolla produces nectar. This collects in a small flat pocket at the base of each petal; the pouch is simply a scale-like outgrowth from the surface of the petal attached along its sides and lower edge.

The *stamens* average thirty-five in number; they are arranged in a close spiral. The pollen is dry and dusty.

The *carpels* are apocarpous (p. 86) and numerous; they also occur spirally (not very clearly so) on a convex receptacle. The average number is twenty-five; they vary between twelve and forty. The ovary is pear-shaped; no style is present; the stigma, soft and warty-looking, is a crescent-shaped bifurcation. The one cell of the ovary contains one ovule.

The Passage from Bud Stage to Fruit Stage

Strictly speaking, the flower-buds are neither winter resting buds like those of deciduous trees, nor spring buds like those of Broad Bean. They come into existence in mid-winter and they have to weather months of severe conditions. The bud-wrappings do not give the impression of being very substantial, yet the wastage of buds seems extraordinarily small. No scales, hairs, resin, or other device is present; the sepals form the only covering. Their best protection is due to their being kept down amongst the plant's own leaves for a long time, and in the fact that the plant keeps its growth close to the ground until flowering is imminent.

A bud whilst still deep within the leaf-bases is at a stage which shows well the relative advancement of the several whorls. The sepals are fully formed, naturally; this is the time when their work of encasing the other whorls is most needed. They fit like a skull-cap, forming at the apex a three-layered covering. Their wrinkled bases are prominent. The petals are green, short, very backward. The stamens are also green, but well enough grown to overtop the petals. The ovaries are almost transparent. The varying advance made by the different members and the change of colours are interesting to follow as the bud grows older.

The time comes when the petals are long enough to push aside the sepals. The burnish is put on the petals directly they are exposed to the light.

The stamens reach maturity well before the carpels. This comparatively early ripening of the andrecium is given the name of *protandry*; it must be considered in connection with pollination.

We will look now at the wide-open flower. The outer stamens are dehiscing (i.e. shedding their pollen); they rise up one by one and move outwards from their central positions, first to stand erect, and then to lie flat on the petals. The pollen sacs open longitudinally; the slits are at the side, and the pollen in falling out sideways is liberally scattered inwards as well as outwards; the stigmas are not yet ready to make use of it. The sepals stand as three points of support for the petals. The flower closes at night, but the sepals never completely cover it again.

Finally, the stage is reached when all the pollen is dispersed; by that time the stigmas are receptive. Pollen hangs for a long time on stamens and petals, and when the flower closes at night there is every chance for it to reach the stigmas of its own flower. That is, self-pollination is possible.

Night closing now ceases. All parts except the gynecium begin to wither; the bright gold of the petals gives place to grey; they curl tightly backwards, only the unglazed part being visible.

The fruits enlarge; the floral envelopes drop off; the flower-stalk weakens, bends and falls prostrate. The fruiting heads do not bury themselves as is sometimes stated. The fruits ripen as they lie; their frail connection with the receptacle gives way and they sink into the loose soil; very soon the vegetation springing up around hides all trace of them. From observations made it appears that rather fewer than half of the ovaries ripen into fruits.

Both self- and cross-pollination are possible. As a result of the protandrous habit, the pollen shed from the anthers which open first is of service only to other flowers. However, at the time when the stigmas are tumid and receptive, every part of the flower is dusted with its own pollen, which, when the flower closes, may adhere to the stigma. In addition to this, crawling insects may make the pollen-transference.

Facilities for cross-pollination are not lacking. Insects visit the flowers in great numbers in favourable weather. On one sunny day in a field on the limestone fells, every flower was noticed as having an insect visitor. They were gathering both pollen and nectar. To get at the nectar, a fly places itself lengthwise on a petal and dips its head downwards between the petal and the stamens; the latter are shaken and pollen drops on the intruder's head. Other insects, in search of pollen, after using the petals as an alighting platform, clamber on to the disk of stamens, amongst which their legs are soon busy scraping up and transferring pollen to their pollen-carriers. Dung-flies, Honey-bees, *Thrips*, were amongst the callers on the fell plants. As a contrast, a garden plot which was watched for several hours on a warm bright day in April had only one insect visitor to its flower-clumps; this spent ten minutes on one flower, and then went off.

CLOSING MOVEMENTS OF THE FLOWER

During that period of its existence within which it is shedding pollen (approximately), the flower responds to certain external stimuli by closing together in lax bud form, whilst remaining upright. The sepals remain nearly horizontal; the petals fold lightly together; there is no opening at the top, but the fitting is so slight that water can and does slip in.

In unshaded places the flowers open between 7 a.m. and 8 a.m.; shaded flowers may still be half-closed at 10 a.m. Afternoon closing begins between 4 p.m. and 5 p.m.; by 5 p.m. all the plants in the bright sunshine of a warm, windless day, even on an open field, may be found closed. In the shade they begin to close at 3 p.m. It is not easy to determine the part played by change of temperature as distinguished from that due to change in illumination. Many observations require to be made, not only on plants in the open, but also experimentally within doors. On a dull day, even if it is not cold, flowers may never open more than half-way; on the other hand, bright sunshine will not tempt them open if a cold wind is blowing. They close also against rain. They seem to be very sensitive to small changes in heat and light. The plants on opposite sides of a bank open and close at different times. One may watch the quick change which comes over the flowers directly the shadow of a bush touches them.

FRUIT AND SEED

The fruit is an *akene*. This is a dry indehiscent fruit formed from one carpel; examples of it are to be found in the Buttercup, Strawberry, Rose, Dandelion, Grass, Wild Clematis, etc. In Buttercups the collection of akenes is seated in the open on a receptacle which is little altered; in the Cornfield Buttercup the akenes are spiny. In the Rose, the receptacle has fashioned itself as a vase, and within that lie the akenes, which are coarsely hairy (Fig. 34). The akenes of the Strawberry are the seed-like bodies dotted over the greatly enlarged receptacle. In the akenal fruits of Grasses, fruit-coat and seed-coat are fused. In Wild Clematis, each akene is topped by the style, which has grown long and feathery. Each flower in Coltsfoot, Dandelion, etc., possesses one akene which has arisen from an inferior ovary; this is the term generally used for these fruits, though they do not conform to the definition in that they are derived from two carpels. The calyx persists in the fruit as a circlet of hairs which carry the fruit through the air (Fig. 59). The grouped fruits of the little florets in these flower-heads must not be confused with a single many-akened flower like a Buttercup.

The *follicle* resembles the akene in being formed from one carpel, and in being dry. It differs in that it opens. It dehisces along its inner edge (the *ventral suture*), whereas the pod splits along both sutures. Amongst others the following have follicle fruits: Marsh Marigold, Columbine, Monkshood, Larkspur.

The examination of the Celandine seed is not easy. Press the akene gently at one end and a nearly spherical body slips out. This is the seed (Fig. 32). Within the testa lies a white sphere, solid at first, but in which there arises a cavity which fills with milky fluid. Both solid and liquid are endosperm. Even with a hand lens you will see nothing that you can be sure of as being the embryo; higher magnification reveals a minute object lying within the milky endosperm. This is an extraordinary type; its development has not gone as far as even the outlining of the usual parts of an embryo.

THE SEEDLING

It has been asserted frequently that few Celandine seeds mature, that those few rarely germinate, that in such as do germinate progress is extremely slow, and that the plant is propagated almost entirely by tubers. Rarity of seedlings, however, is not at all characteristic in connection with the "fertile" type of plant. As soon as you know what shape of leaf to look for, you will get seedlings sheltering under the leaves of almost every clump of flower-bearing individuals, in April, May and June. They have been found amongst the plants of the pasture field; where adult Celandine had to push through three inches of dead leaves, seedlings were following suit; beautifully fresh and strong young plants had quarters in damp hollows amongst grass and nettles. In a cultivation plot, which for two years had given only a few flowers, seedlings appeared. One autumn a cluster of tubers within their slab of soil was brought home to keep under observation: by the end of February, within a space three inches in area, there were counted twenty-nine seedlings.

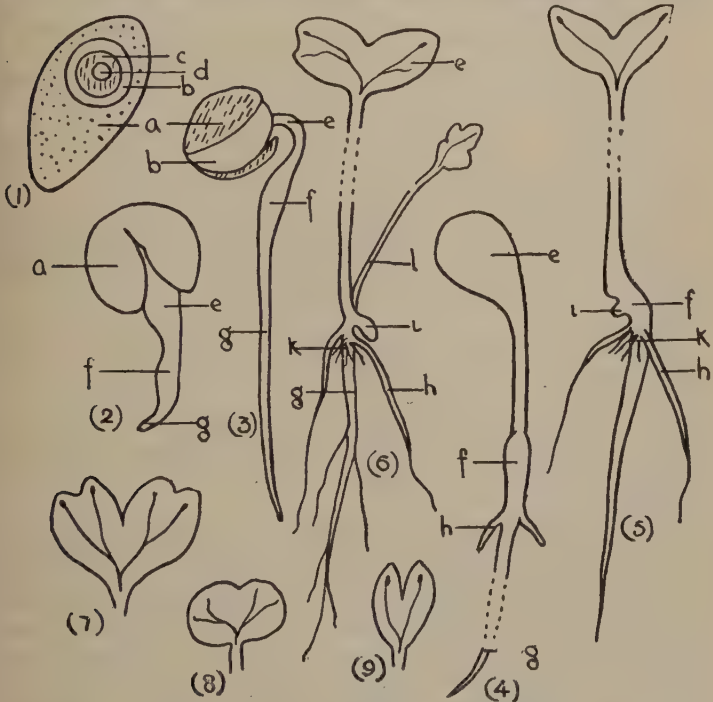

Fig. 32. Lesser Celandine: Seedlings

(1) Ripe seed: more highly magnified than others; (2)–(6) Seedlings in successive stages of development; (7)–(9) Types of cotyledon.

a, wall of fruit; *b*, seed-coat; *c*, white, solid, spherical mass of endosperm; *d*, fluid endosperm in which lies embryo; *e*, cotyledon; *f*, hypocotyl; *g*, radicle; *h*, secondary root; *i*, tuberous root; *k*, circlet of hairs; *l*, first foliage leaf.

Seedlings may be reared from seed in water in glass tubes, or may be collected at various stages and watched as they develop. The sketches on page 75 were made from two or three specimens.

In Fig. 32 (2) the parts of the embryo lie in a nearly straight line—radicle, hypocotyl and cotyledon can be made out, the last still within the testa.

In Fig. 32 (3) the radicle is much longer; the petiole of the cotyledon is lengthening and is forced, in doing so, to curve, because its two ends are fixed. The cotyledon always issues from the ground in "arch" form.

In Fig. 32 (4) two lateral roots have arisen just below the cotyledon. The latter is now free; its two halves are folded face to face. It is remarkable that there is only *one* cotyledon, for this is a plant you might expect to belong to the Dicotyledons (p. 93).

In Fig. 32 (5) a ring of hairs has appeared immediately below the lateral roots, additional to the usual root-hairs. A slight bulge is increasing on the under side of the hypocotyl. The cotyledon has opened out.

A week after this drawing was made, the swelling on the hypocotyl was seen to be a tuber, the first. The green tip of a leaf was visible above the tuber. In the natural course of events the terminal bud of the axis, i.e. the plumule, would be situated between the two cotyledons (compare the Broad Bean). Here it was pushed to one side and looked as if it were in the axil of the cotyledon.

In Fig. 32 (6)—again the same seedling, but eighteen days older still—there has emerged fully a foliage-leaf with a seven-lobed margin. More lateral roots have formed.

In a fortnight the tuber was 3·3 centimetres long, the radicle was decaying, a second foliage-leaf lay within the first. From this time until the end of the season, when fibrous roots and foliage rotted off, there was little change.

The cotyledonary organ is unique (Fig. 32 (7, 8, 9). First of all, we expect two seed-leaves and we find only one; that, however, is not quite peculiar to this plant. Founded on the details of its development as well as on its adult characters, there is a belief that it represents a fusion of two cotyledons. There are other, less complete, fusions known within the Buttercup Family. The next notable fact is that the seed-leaf bears no resemblance to the first foliage-leaf of a tuberling or a seedling, and is no simpler in form. Its outline is somewhat variable, but it is always bifid, the two halves lying right and left of a central crease; the central indentation may be deep enough almost to cut it in two. The veining systems of the two lobes are independent after they leave the petiole, and it is noticeable that no central vein runs up the crease. These points are taken as evidence of the union of two leaves.

The summary of the results of a seedling's activity in one season is this: a radicle, lateral roots, a first tuberous root, a hypocotyl, one cotyledonary organ, and one or two foliage-leaves.

Everything disappears at the end of June except the node which stands for the hypocotyl, the tuberous root arising from its lower side, and the plumular bud on its upper side, which is the resting bud for next season's growth. There is no bud on the tuber, and in this it agrees with the first long tuber in an adult plant. Compare this resting seedling with a resting tuberling.

The "Sterile" Plant

Nothing about *Ranunculus Ficaria* is more surprising, nothing farther from being explained, than the existence of the two types of plant. A great deal of information has been collected which would be out of place here; much more must be done before the main questions can be considered to be answered.

Aerial tubers are never found on fertile plants: a few miserable flowers may be found on sterile plants. Fig. 29 gives an idea of sterile plant form. Tubers are present at every node of a sterile plant. They at first lie hidden within the broad bases of the stem-leaves; they grow upwards and remain short and sub-spherical, or they grow parallel with the petiole for a time and then turn downwards, or they at once pierce downwards through the leaf-base. In outward appearance they are indistinguishable from ground tubers. Fine root-hairs cover them and are seen in perfection within the axillary chamber. The root-cap can be identified. The aerial tubers rise from the nodes of the stem; it can be proved for them as it was for the ground tubers that they are modified roots. Every one of them bears a bud. Sometimes this bud sprouts whilst the tuber is attached, and gives rise to a few delicate leaves which resemble strongly the first leaves of a young plant (Fig. 31). There may thus be formed on the parent plant little "tuber" plants. The few flowers on sterile plants are usually malformed and insignificant; the scanty pollen may never mature. The leaves of the sterile plants are fairly characteristic (Fig. 31).

Although no quite conclusive evidence has yet been found, what does exist points to the habit of bearing aerial tubers as being a fixed hereditary character. Its present distribution is certainly not dependent either on depth of shade or heavy water-content of soil.

Dispersal of Plants

No provision is made in Lesser Celandine for dispersing seeds to a distance. Unless the habitat happens to be exposed at seed-time in such a way that water or wind may carry off the seeds, they germinate within a few inches of the plant which bore them.

But the tubers, both ground and aerial, may take long journeys. This is true especially of those left ill-covered with soil on the slopes leading down to a stream; a heavy shower of rain may sweep them down to the stream in handfuls, and their wide distribution is thus assured.

In a level pasture-field, neither wind nor water can help much. The most likely means of carriage is on the hoofs of sheep, cattle and horses, by which the turf is cut up and the tubers laid bare; often they are carried about on these hoofs.

Quite commonly, tuber and fruits remain where they are, and the consequence is a badly crowded community in which hundreds of young plants will be checking one another's growth.

CHAPTER VII

THE CLASSIFICATION OF PLANTS

At an early stage in the history of botanical science, workers began to classify plants. Various schemes were made and rejected before the classification now generally in use was arrived at; even within that there exist points on which there is disagreement. From the material which the reader of this book is supposed to have examined, he may now make a beginning with systematic classification. His best plan is to proceed from smaller groups to combinations of these into larger. He has detailed knowledge of the Lesser Celandine. Let him procure and make comparison notes on a number of flowers which obviously resemble it, setting out the details in which they agree, and those in which they do not. This is the list:

(1) Upright Meadow Buttercup or Acrid Buttercup. The tallest of our Buttercups. Flowers great part of the year. Long underground stem. Flowers yellow, sepals spreading. Peduncles rounded, leaves segmented.

(2) Creeping Buttercup. Smaller than (1). Shorter upright stem, but sends off prostrate branches which root at the nodes and give rise to new plants. Flowers May to September. Leaves with broader segments. Flowers yellow, sepals spreading, peduncles furrowed.

(3) Bulbous Buttercup. No runners. Stem is erect and swollen at base as storage organ, a corm. Flowers in late spring. Lower leaves broad and many-lobed; upper with few narrow lobes. Flowers yellow, smaller; sepals distinctive, being bent back against the flower-stalk. Peduncles furrowed.

(4) Cornfield Buttercup. Differs from the other three in being an annual; a weed ripening amongst the corn. Leaves divided, with broad clasping bases. Flowers yellow, petals five, sepals five. Fruits are akenes with curved spines. Peduncles not furrowed.

(5) Goldilocks. Tall, but of lower and less substantial growth than (1). Cauline leaves sessile. Flowers yellow, great variability in number and shape of petals. Nectar-pocket has no scale.

(6) Spearworts, Greater and Lesser. Differ from the first five (the Crowfoots) in having undivided lanceolate leaves. The Greater has a stem creeping at the base; the Lesser a stem strongly erect. Flowers yellow.

(7) Lesser Celandine. Stem and tuberous organs peculiar to it. Leaves undivided, palmate-veined, sheathing bases. Flowers yellow. Sepals and petals vary in number.

(8) Water Crowfoots. Aquatic plants. Leaves very variable, correlated with depth of water. Flowers white.

You will find from your examination of specimens that the above-mentioned plants agree in the following particulars: (*a*) The flowers are regular, (*b*) in not one of the whorls are the parts united, (*c*) sepals differ from petals, (*d*) stamens and carpels are indefinite in number, (*e*) nectaries are present on petals and are fairly accessible, (*f*) the fruits are akenes. The general floral formula is $K3{-}5$ $C5$ $A\infty$ $G\infty$. There are unspecified plants which belong to this group; look for them. On the ground of their points of similarity all these plants are regarded as being closely related, and are given a "class" name. They constitute a *genus*, the genus *Ranunculus*.

To each member of a genus there is given a second name to distinguish it from the other individuals in the genus; it forms a *species*, and is allotted a *specific name*, which is placed after its *generic name*. For example, the Creeping Buttercup is *Ranunculus repens*. The generic name is spelt with a capital letter, the specific (with certain exceptions) with a small letter. The scientific names corresponding to the popular names in the list given above are: (1) *Ranunculus acris*, (2) *R. repens*, (3) *R. bulbosus*, (4) *R. arvensis*, (5) *R. auricomus*, (6) *R. flammula* and *R. lingua*, (7) *R. Ficaria* (a capital letter is given to *Ficaria* because the plant has been regarded as a separate genus, *Ficaria verna*), (8) *R. fluitans*, *R. heterophyllus*, etc.

Now examine the characters of the twelve plants described below; each one of them is representative of a genus of the same rank as *Ranunculus*, which is given its place amongst them.

(1) Traveller's Joy (*Clematis Vitalba*). This differs from all other Ranunculaceæ in being a shrubby climber. The flower is regular, has four large greenish-white sepals and no petals. Stamens and carpels are numerous and spirally arranged. The carpels are free. The fruit is one-seeded, an akene. No nectar is secreted.

(2) Wood Anemone. The flower is white, tinged with pink, and regular in form. Some way down the stalk is a circlet of three leafy bracts. The coloured members are sepals, varying from five to nine; petals are absent. Stamens and carpels are numerous and spirally arranged. There is no nectar; cross-pollination is effected by insects in search of pollen; self-pollination is possible in the later stages. Some members of the anemone group (e.g. Pasque Flower) possess nectar. Fruit is one-seeded, an akene.

(3) BUTTERCUPS. The flowers are regular, and yellow or white. The number of members in the two outer whorls is variable. Stamens are numerous, spirally arranged; carpels are numerous, free, spirally arranged. Nectar is rather freely exposed, in pockets at bases of petals (Fig. 63).

(4) MARSH MARIGOLD. The flower is showy, golden yellow, and regular. There is no distinction into calyx and corolla; the sepals, five to nine, are coloured. Stamens are numerous, spirally arranged. Carpels are five to ten and free; in depressions at their bases is collected the nectar, for there are no special nectar-producing leaves. The fruits are follicles containing several seeds; they split along the seed-bearing margin for a little way from the top; seeds are shaken out (censer mechanism).

(5) MEADOW RUE. The general appearance is strikingly unlike that of the other flowers in this Family. Above the fragile, compound leaves rise clustered inflorescences which look to be wholly composed of pale yellow stamens. The perianth of thin yellowish sepals drops off early; there are no petals. Stamens are numerous. Carpels are few, may be reduced to three; they are one-seeded, and the fruit is an akene. There is no nectar. The Rue of the chalk pastures is pollinated by wind; that of moist places by flies in search of pollen.

(6) GLOBE FLOWER. The large yellow flower is nearly globular, owing to the perianth remaining closed practically all the time. The plan of the flower is regular. The outer members are variable in number (five to fifteen), and have indications of spiral distribution on the receptacle; they are petaloid sepals. The next set, similar in number and arrangement, are honey-leaves (possibly modified petals); they are flat and narrow, the nectary being in a pit at the base. Stamens are numerous. There are five or more free carpels which ripen into follicles. The flowers are usually self-pollinated.

(7) WINTER ACONITE. This is a very early spring plant, rising from a thick rhizome. The flower has an involucre of bracts close to it on the peduncle. There are six or seven yellow sepals—the attractive part. Within these stand six or seven yellow tubular structures which contain nectar; they are generally regarded as modified petals, though some botanists regard them as stamens. There are about thirty stamens, and, on an average, six carpels (range is three to eleven). The carpels ripen into follicles. The flower is protogynous. It protects its nectar and pollen by closure movements.

(8) CHRISTMAS ROSE. The flower is large, white, drooping, regular. The five or six sepals are petaloid. Internal to these stand, on an average, thirteen tubular, greenish honey-leaves (Fig. 63). There

are about ninety stamens. The carpels, usually five, may be only three; they are slightly joined at the base, which is a point of importance. They ripen as many-seeded follicles. The flowers are protogynous.

(9) MONKSHOOD. The flower is dark blue to purple, and is very irregular. The attractive part consists of sepals. These are placed as two anterior and lower (for the flower is horizontal), two lateral above these, and one shaped like a hood which arches down over the upper half of the flower. A corolla, as such, is wanting; in its place are three scales and two stalked nectaries (Fig. 64). The latter are hidden under the hood which also protects the pollen from rain. Stamens are numerous. Carpels are usually three. The fruits are follicles, and the stalk straightens up when they are ripening. The flower is protandrous. It is pollinated solely by Humble Bees. They light on the platform of sepals and push their heads up under the hood; if the flower is in the staminate stage, they get pollen on their under sides; if, subsequently, they visit a flower in the pistillate stage, the pollen they carry will have a good chance of getting to the ovaries there, for the stamens of that flower will have turned back out of the path by that time. This is a good example of the way in which protandry may be an advantage. Insects sometimes get at the nectar by biting through the tubes. In course of their visits to an inflorescence of Monkshood, Bees start with the older flowers at the bottom, which are in the female stage, and work upwards, ending with the younger, higher, in the male stage.

(10) LARKSPUR. The flowers are rich blue and markedly zygomorphic. The five sepals are petaloid; the posterior sepal is prolonged at the base into a long curved tube or " spur." Only two of the petals are petal-like, the pair lying on each side of the sepal-spur. Parts of these also become altered; two strips, one from each, join, first as a tube and then at their tips, as a solid nectar-secreting gland. This second " spur " grows down into the spur of the sepal. No other trace of petals exists except, sometimes, two minute scales. The stamens are indefinite, but not as numerous as in Buttercups. The carpels are free and vary from one to five. The fruit-stalk erects itself; the fruits are follicles. The open flower is horizontal; Humble Bees are the successful visitors. They light on the lower sepals, and only one way in is left to them, as the side petals partly close the opening. Honey can be got only by long-tongued insects. The double walls of the spurs make it difficult for insects to bite a way in to the nectar.

(11) COLUMBINE. This is a very showy flower; both sepals and petals are bright-coloured, often deep blue. There are five of each. Both sets have long-spurred bases. The spurs of the petals are thrust outwards between the sepals; their extremities are thickened, and

secrete nectar which collects in the tube. The flower droops, but the nectar is retained in the curved tips of the spurs. The stamens are indefinite, but some of the inner ones produce no pollen (*staminodes*), which suggests that the number is in course of reduction. There are five carpels which are joined at the base. The fruits are follicles, and as they are erect the seeds have to be shaken out. The flower is protandrous. It is pollinated as in Larkspur and Monkshood.

(12) Love-in-a-mist. The most striking feature is the feathery collar of much-cut bracts which surrounds the bright-blue flower. The five sepals are the petaloid parts. In place of the petals there are from five to eight small tubular honey-leaves provided with lids which prevent small insects from reaching the nectar. The stamens are numerous. The ovary is exceptional. The carpels are five, and are *joined* to form a five-chambered ovary. Each carpel has a free tip and a separate style. The fruit splits from the tip down the partitions. The flower is protogynous. The styles, at first erect, may bend over before all the pollen is gone, and self-pollination is likely to take place.

The generic and specific names of these plants are: (1) *Clematis Vitalba*, (2) *Anemone nemorosa*, (3) *Ranunculus* spp. (i.e. various species), (4) *Caltha palustris*, (5) *Thalictrum flavum*, (6) *Trollius europæus*, (7) *Eranthis hyemalis*, (8) *Helleborus*,[1] (9) *Aconitum napellus*, (10) *Delphinium*,[1] (11) *Aquilegia vulgaris*, (12) *Nigella*.[1]

The genera enumerated (plus others not mentioned) have characters in common; make a list of these. They will be found to include the following: they are herbs with alternate leaves (*Clematis* is an exception); the flower is hypogynous; both stamens and carpels are present and are arranged in spirals; stamens are numerous; carpels are variable, often numerous, and generally free; nectar-bearing leaves are very common; fruit is a collection either of akenes or of follicles. Having noted the resemblances which link these plants together, compare them with Roses, Daisies, Foxgloves, etc. They clearly belong to separate groups. The genera most closely allied with *Ranunculus* are placed together as one *Family*; their Family name is *Ranunculaceæ*, the distinctive characters of which are those mentioned above.

The technical description of Lesser Celandine will be:

Family . . .	Ranunculaceæ
Genus . . .	Ranunculus
Species . . .	Ficaria

The system of classification will be carried farther on page 93.

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[1] Cultivated species.

FAMILY: RANUNCULACEÆ

This is a Family of peculiar importance in the system of plants, by reason of the astonishing range of variation in many parts of its plants.

The habitats are very diverse. Water Crowfoots inhabit water of varying depths, in ponds, ditches, slow-flowing streams, mud-flats. They have heterophyllous leaves and specially adapted tissues (p. 85). Marsh Marigold is found in damp meadows, by the sides of streams, even washed by the stream water when seated on little mounds in the stream. It has a thick perennial rhizome, and many air-spaces in its tissues. The Lesser and the Greater Spearwort are also characteristic of wet places; Meadow Rue favours the river banks.

The Wood Anemone thrives as colonies in fairly deep shade in woods, able to flower early because of its storage rhizome. The thin tall stem of Goldilocks springs up in the woodland thickets. Lesser Celandine has many habitats, woodland included (p. 61).

The Buttercups belong more particularly to grassland. The Meadow Buttercup sends its long roots below the shorter roots of Grasses, Daisies, etc., and this achieves success below ground. It sends its seeds high on long stalks, and in this also is a good competitor. The Creeping Buttercup forms loose rosettes of leaves, and can keep a space around it moderately clear of plants. Its roots are in short bunches. It sends out long creeping stems on the surface of the ground; at every node of these, adventitious roots may strike downwards and a new plant develop; a regular colony is created. This plant spreads intolerably rapidly on cultivated ground. The Bulbous Buttercup also belongs to the pastures; its best chance depends on its early flowering period, which is dependent on the corm-like structure. The Globe Flower is a plant of the grass-fields, often high-lying fields. The Cornfield Buttercup grows amongst the cereal crops.

Columbine is a limestone-loving plant, but is not commonly found wild in Britain. In cultivation it responds readily to crossing, and many beautiful variations appear. Clematis grows well in limestone soil. Its petioles, used as tendrils, fit it as a hedge climber.

The variation in leaves may be summarised. We have already seen what variation there is in the Celandine's leaves (p. 68). Many of the Buttercups (*Ranunculus acris*, *R. repens*, *R. bulbosus*, *R. arvensis*) have divided leaves with broadly sheathing bases. Columbine and Anemone have segmented leaves; the five leaves forming the involucre of Love-in-a-mist are cut up into very narrow strips; Meadow Rue has much-branched compound leaves. In Winter Aconite and Monkshood the leaves are palmately lobed. The leaves of the Marsh Marigold are undivided, strong, cordate in shape, and possess very large stipules; they are glossy.

Many plants within the Family illustrate what has been mentioned about two forms of leaf on one plant. In the Globe Flower, the radical leaves are rounded, five-lobed and petiolate; the cauline are smaller and sessile. The Spearworts generally have undivided lanceolate leaves, but in the Lesser Spearwort the lowest leaves on the stem are ovate. In Goldilocks, the radical leaves are orbicular, those in the stem are cut into segments. The leaves of Larkspur have many narrow, linear lobes; the lower are petiolate, the upper sessile. Plants with two forms of leaf are *heterophyllous.*

The leaves of Water Buttercups are the most striking. When the plant grows in muddy soil, its leaves are rounded and slightly lobed. It can grow entirely submerged in water, and then every leaf is cut into narrow ribbons (Fig. 33). In shallow water, a combination of the two forms prevails; such of the leaves as are within the water are filamentous, whilst those which rise above it are like the leaves of the mud plant. In such circumstances, the much-divided form of leaf has two great advantages. First, the increased and widely spread leaf-surfaces favour the acquisition of oxygen, etc., from the limited supplies in the water. Second, a leaf already in strips runs less risk of damage from currents of water.

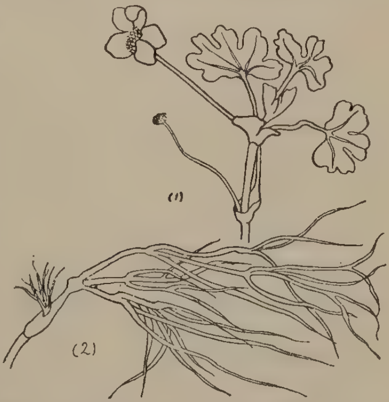

FIG. 33. LEAVES OF WATER BUTTERCUP
(1) Aerial leaves; (2) Submerged leaves.
Example of heterophylly.

Traveller's Joy (*Clematis Vitalba*) is the only member of the Family which has opposite leaves; they are also pinnate. The plant is shrubby in habit, and the petioles by twining act as climbing organs.

Amongst the above examples you will find evidence that leaves have adapted themselves to their habitats, and you will recognise reasons why leaves at different levels on the same plant may vary.

Nectaries are absent from some flowers of this Family; insects in those cases pay visits in order to get pollen. In the list given below typical plants are arranged, approximately, according to the accessibility of the nectaries.

BUTTERCUPS. A scale-pocket at the base of the petals in an open flower. In the Celery-leaved Buttercup the scale is wanting.

MARSH MARIGOLD. At the bases of the carpels in an open flower.

CHRISTMAS ROSE. Petals become tubular and function as nectaries.

WINTER ACONITE. The honey-tubes stand outside the rows of stamens and may be stamens.

COLUMBINE. Each petal ends in a long curved spur; the nectary is at the end of this.

LARKSPUR. The large posterior sepal has a long spur at its base; processes from the two upper petals lie in this, and their united solid ends are the nectary.

MONKSHOOD. Two posterior petals are modified into stalked nectaries and placed under the hood of the posterior sepal.

Wood Anemone and Wild Clematis are pollen flowers; they produce no nectar.

By many, Ranunculaceæ is regarded as a group which may have had representatives amongst the earliest flowers evolved; they also trace within it a progression from these more primitive types upwards to more elaborate, more successful forms of flower. They would regard a Buttercup as being very low down in such a scale, and Monkshood or Larkspur as being about the top of it. They regard certain characters as indications of the improvement in form. Take each of these characters in turn and trace its occurrence amongst the plants you examine; decide for yourself how far the theory holds good. The characters are as follows: (*a*) It is supposed that in the first flowers the floral members, probably numerous, were arranged on the axis in *spirals*, and that the setting of them in distinct whorls (*cyclic* arrangement), one above the other, came into existence by stages. Compare Globe Flower and Larkspur. (*b*) There is a sequence from an indefinite and large number of parts to a definite and much smaller number; this applies especially to the stamens and the carpels. Trace the line from Buttercups to Larkspur. A hint of the way in which stamens disappear is given in the staminodes of Columbine. Larkspur has gone very far in sometimes possessing only one carpel. (*c*) That several ovules are enclosed in one carpel instead of one in each of several, and—which is of more moment, perhaps—that several carpels join and form one structure, is considered an advance in plant construction. It embodies the change from apocarpy to syncarpy. It begins in this Family by the substitution of follicles for akenes. There is, in Christmas Rose, a slightly syncarpous condition; Nigella has arrived at a five-chambered syncarpous gynecium, the components of which are indicated only by the free styles. (*d*) In three particulars the flowers seem to become better suited to insects, particularly to the higher insects. Compare the regular flower of Buttercup with the irregular flowers of Larkspur and Monkshood. The very irregularity of the latter calls attention to them; some of the perianth parts provide a landing-stage for Bees; others make effective tents over pollen and nectar; others place themselves as guides to keep the insect in the track most favourable to the flower. Nectar is a common attraction. The advance connected with it lies in the skill with which it is reserved for visitors who will be sure to take up pollen on their way to the honey-store. Honey in the scale-pockets of the Buttercup saucers is free to almost anybody; but in Columbine it takes the long tongue of a Humble Bee to get at it. In a few plants there is no nectar; in Traveller's Joy this is associated with characters which are supposed to be primitive. It is generally considered that the colours of the flowers within this Family show gradation in their adaptation to the fancy of the higher insects. The scheme begins with the more elemental white and yellow, and rises to what are said to be the favourite colours of the Bees, namely, blue and purple.

The aim, so to speak, of the flower is to make sure that the ovules are pollinated, and, if possible, by pollen from another plant; with many stamens and many carpels the principle is to offer many chances, with the possibility of one succeeding; this involves wasteful expenditure of material. It is a sounder plan to economise by making sure of each opportunity offered. In (*a*), (*b*) and (*c*) we see how this is attempted. In (*d*) there is seen the provision for cross-pollination.

The facts relating to this subject should be set out in a table, the various columns of which can then be correlated for each plant. For example, it may be noted whether or not union of parts is correlated with high-grade colour, concealed nectar, etc.

FAMILY: ROSACEÆ

The Family to which the Roses belong may be conveniently considered after that of the Buttercups. A Rose and a Buttercup are not likely to be mistakenly grouped together, but we need some class characters to separate the Buttercup from the Creeping Cinquefoil, which belongs to the Rose Family. The Rose gives the name *Rosaceæ* to its group; the chief distinguishing characters are the following:

Leaves. Varied, simple, palmate, pinnate; large stipules common.
Inflorescence. Racemose or cymose.
Flower. Regular, generally perigynous.
Sepals. Four to five. Epicalyx often present.
Petals. Four to five, free.

Stamens. Indefinite.
Carpels. Variable, often numerous, usually apocarpous.
Fruit. Many types (see below).

This Family bears general resemblances to Ranunculaceæ in the regularity of the flowers, the separation of members of whorls, the large and variable number of stamens and often of carpels. It differs in having perigynous flowers, and often in its stipulate leaves. Pollination is by insects, except in some reduced forms; there are no special devices for attraction. There is a great variety of form, including trees.

Three plants have much-modified flowers. Lady's Mantle has flowers with no corolla, only four stamens and one or two carpels; they are small and green. The Great Burnet has purple flowers, but again a corolla is wanting and the stamens are only four; it is insect-pollinated. The Salad Burnet has greenish-purple, globular masses of flowers. The upper flowers in the inflorescence are female, and are reduced to a calyx and a feathery outstanding stigma; the lower are male, and consist of a calyx and numerous stamens with long filaments. The upper flowers open before the lower; they are wind-pollinated.

Fruits of Rosaceæ.

Wood Avens. Many akenes with long, hooked styles (Fig. 34).

Water Avens. After pollination the receptacle lengthens between the disk and the gynecium, and carries above the calyx the clusters of akenes tipped with hairy, hooked styles.

Cinquefoil, Tormentil, Silverweed. Fruits are one-seeded. The carpels are closely arranged on an open, dry receptacle. They resemble those of Strawberry except for the fleshy growth.

Lady's Mantle. One or two akenes are more or less completely enclosed in a hollow receptacle.

Agrimony. One or two akenes are embedded in a small woody receptacle provided with hooks.

Salad and Great Burnet. One or two akenes are enclosed in a four-angled receptacle.

Meadowsweet. Five or six follicles, each with two to six seeds, stand on a nearly flat receptacle.

Sloe. Drupe, small, round. The inner part of the carpel hardens and becomes the stone covering its seed.

Plum, Cherry. Drupes. Single carpel with two ovules.

Blackberry, Raspberry. Cluster of drupels. Each carpel has two ovules. The broad receptacle has an elevation in the centre like the Strawberry, but it remains small. The carpels become succulent drupes.

Strawberry. Akenes are seated on a convex, much-swollen receptacle. Each carpel has one ovule. The enlargement into a succulent mass depends on the fertilisation of the ovules.

Rose. The receptacle is deeply hollowed, constricted at the top. There are many free carpels attached to the bottom and sides of the urn; their styles and stigmas protrude from it. Carpels become akenes with hard pericarps; the receptacle becomes fleshy.

Apple, Pear. Fruit is a pome, the main part of which is formed from the receptacle. Ovary is inferior and five-chambered, in each carpel two ovules. The outer part of the carpel wall becomes fleshy and fuses with the "flesh" of the receptacle; the thin, tough endocarp lines the seed-chambers. Remains of calyx, corolla and stamens may be seen on the top of the fruit.

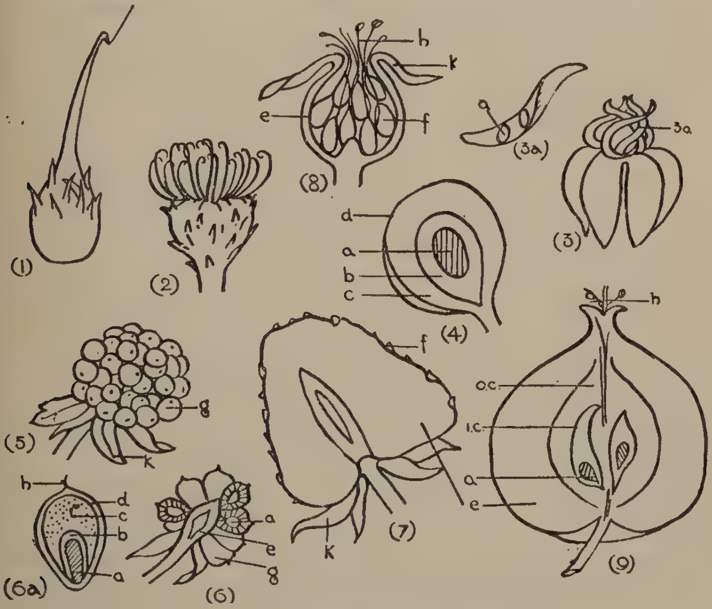

FIG. 34. FRUITS OF ROSACEÆ

1) Wood Avens, one akene; (2) Agrimony; (3) Meadowsweet, collection of twisted follicles; (3*a*) Enlarged follicle from 3; (4) Sloe, longitudinal section; (5) Blackberry, cluster of fruits; (6) Blackberry, longitudinal section; (6*a*) Single drupel from 5; (7) Strawberry, longitudinal section; (8) Rose-hip, longitudinal section; (9) Apple, longitudinal section.

a, seed; *b*, endocarp; *c*, mesocarp; *d*, epicarp; *e*, receptacle; *f*, akene; *g*, single fruit-drupel; *h*, stamens; *k*, calyx; *i.c.*, inner part of carpel wall; *o.c.*, outer part of carpel wall.

Hawthorn. Fruit is a small pome. The one or two carpels become adnate with the receptacle; their walls become hard, comparable with the tough Apple core.

Rowan. This is an intermediate form leading to Apple and

Pear. The upper parts of the carpels remain separate in the centre of the flower and have separate styles.

An epicalyx is present in Strawberry, Avens, the Potentillas, Lady's Mantle, etc.; it is absent from Cherry, Plum, Meadowsweet, Burnet, etc. An interesting series, illustrating the upgrowth of the receptacle, may be selected from this Family. In such as Meadowsweet, Strawberry, Blackberry, there is seen the nearly flat receptacle and the simplest condition of perigyny. In the Plum and the Rose perigyny is marked. In Rowan, Pear and Hawthorn there is epigyny.

Typical Habitats of Rosaceæ.—Plums, Cherries, Apples and Pears are small trees—cultivated or hedgerow plants. The Sloe, the Hawthorn and the Rowan are shrubs or small trees of hedge or copse. The succulent, attractive fruits of all the above are exposed in situations likely to be found by birds. Roses and Brambles scramble over hedges and thickets, their fruits also juicy and temptingly displayed. Raspberry appears in the more open places within woods and on banks. The Common Agrimony is a hedge plant; Wood Avens, one of the hedge and the wood. Water Avens and Meadowsweet are found in the wetter soils in meadows and near streams.

A group of more lowly plants multiply quickly in a vegetative way. The Strawberry of the woods has small insignificant flowers, but sends out runners at the ends of which new plants form. Tormentil (*Potentilla tormentilla*) spreads its slightly creeping stem under the Heath plants of the moors. *Potentilla reptans*, growing near the wayside hedge, has long creeping stems. The hairy leaves of Silverweed, which also has long runners, decorate waste roadsides.

Lady's Mantle grows amongst the grasses of pasture-land; Great Burnet favours moist pastures. Salad Burnet is a characteristic plant of limestone grassland.

Knowledge already gained may now be gathered together within five other Families of plants.

FAMILY: CRUCIFERÆ

Leaves. Exstipulate, alternate.
Inflorescence. Raceme or corymb.
Flower. Usually regular, nectaries present.
Sepals. Four, free.
Petals. Four, free, cruciform.
Stamens. Six, in two whorls.
Carpels. Two, syncarpous, superior; gynecium divided into two chambers by replum. (Membranous partition)
Fruit. Siliqua or silicula.

Irregular corolla in Candytuft. Sea-rocket has thick fleshy leaves of sea-coast type. The Family contains many cultivated food plants—Cabbage, Cauliflower, Radish, Watercress, Turnip, Mustard, etc.

FAMILY: LEGUMINOSÆ

Leaves. Stipulate, usually compound.

Inflorescence. Raceme.

Flower. Zygomorphic, in British plants papilionaceous, slightly perigynous.

Sepals. Five, united more or less.

Petals. Five, free.

Stamens. Ten, either all united as a tube (monadelphous) or nine united and one free (diadelphous).

Carpel. One, superior.

Fruit. Legume.

The British plants of this Family belong to the sub-Family Papilionaceæ. The other sub-Families are tropical or sub-tropical; they include Mimosas and true Acacias. The two chief differences are that the foreign flowers have numerous stamens (a connecting-link with Rosaceæ), and that their corollas are not papilionaceous.

Leaves and leaflets are often capable of change of position through their pulvinus or swollen base. Many of the plants are climbers. Insect-pollination is general, mostly by Bees. The roots bear bacterial nodules.

The following examples give an idea of the grouping which can be traced within the Family. The Vetches (*Vicia*) and the wild Peas (*Lathyrus*) are herbs with pinnate leaves, tendrils, and a diadelphous andrecium. In Broom, Laburnum, Gorse, Lupin, Petty Whin, Restharrow, we have several shrubs, leaves vary, tendrils are absent, the stamens are monadelphous and there is no honey. Restharrow, Clovers and Medick have trifoliate leaves; the last two are diadelphous.

Individual plants require some notice. Lupin has compound palmate leaves; Broom has much-reduced leaves and a green stem. Restharrow has branch spines; the False Acacia has stipule spines. The Yellow Vetchling's stipules function as leaves, whilst the leaflets are reduced to tendrils (Fig. 6). *Mimosa pudica* is the Sensitive Plant. In some Clovers the fruit is enclosed within the persistent corolla; in some the petals are fused with the stamen-tube. Lady's Fingers, in those species which grow by the sea, is heavily coated with hairs. Lucerne (*Medicago sativa*) is a fodder crop.

FAMILY: LILIACEÆ

Perennial herbs with bulbs, corms or rhizomes. Leaves usually radical, sheathing, lanceolate.

Inflorescence. Usually raceme.

Flowers. Regular, perfect, trimerous.

Perianth. Six-partite, two whorls, free or united, frequently petaloid.

Stamens. Generally six, two whorls.

Carpels. Three, syncarpous; three-partite stigma; ovary superior and three-celled; ovules numerous.

Fruit. Capsule or berry.

Herb Paris varies greatly from type; leaves are broad and net-veined; flower is greenish; whorls four-partite (less commonly five-partite); fruit a blue-black berry. Tulips : no nectaries, visited for pollen. Bog Asphodel : marsh plant, grass-like leaves. Solomon's Seal : strong rhizome. Aerial parts consist of a curving stem with leaves lying in one plane and greenish-white flowers hanging from its under side. Autumn Crocus (Meadow Saffron): flowers in autumn, fruits in spring; very long corolla tube. Lily of the Valley: spreads by rhizomes, which are tipped by the inflorescences. Onion ; inflorescence is a cymose umbel. Leeks and Garlic : bulbils may replace flowers. Butcher's Broom: good examples of shrubby phylloclades (Fig. 83).

FAMILY: AMARYLLIDACEÆ

Perennial herbs with bulbs or rhizomes.

Inflorescence. Cymose, enclosed in membranous spathe of bracts.

Flowers. Usually regular, hermaphrodite.

Perianth. Six-partite, united, petaloid.

Stamens. Six, sometimes epipetalous.

Carpels. Three, syncarpous; ovary inferior, three-celled; ovules numerous; placentation axile.

Fruit. Capsule or berry.

The principal difference between this and the Family Liliaceæ is the inferior ovary.

The most familiar examples are Snowdrop, Narcissus and Daffodil. The drooping flowers of *Snowdrop* are adapted to Bees. When the Bee touches the projecting outgrowths from the stamens, pollen is shaken down on its head; this may be deposited on the next flower visited, the stigma being touched first. In *Narcissus* and *Daffodil* there is an outgrowth from the perianth-tube which is often strikingly beautiful; it is the corona. The Daffodil is pollinated by Humble Bees, and the Pheasant-eye Narcissus by Moths.

FAMILY: IRIDACEÆ

Perennial herbs with bulbs, corms and rhizomes.
Flowers. Regular or irregular.
Perianth. Six-partite in two whorls, petaloid, united.
Stamens. Three.
Carpels. Three, syncarpous; styles, three; ovary inferior; ovules numerous on axile placentæ.
Fruit. Capsule.

The Family differs from Liliaceæ and Amaryllidaceæ chiefly in having three stamens; the inner whorl of stamens is missing. It differs from Liliaceæ in the inferior ovary. *Examples:* Crocus, Iris, Gladiolus. The Iris flower is specially adapted to Humble Bees; its parts should be carefully examined.

Contrast the group of Families containing Liliaceæ, Amaryllidaceæ and Iridaceæ with the group of Cruciferæ, Leguminosæ, Ranunculaceæ and Rosaceæ. You find these pronounced and almost invariable differences:

(*a*) The leaves in the first group are parallel-veined; in the second, net-veined.
(*b*) The floral parts in the first are in three or multiples of three; in the second, five or four.
(*c*) In the first there is one cotyledon; in the second, two.

We have here in outline the division of the Flowering Plants into two groups, each containing many Families. Their names are taken from the last character: they are the *Monocotyledons* and the *Dicotyledons* (cf. p. 83).

CHAPTER VIII

THE PLANT CELL

AMŒBA: A UNICELLULAR ANIMAL

YOU have looked into the stories of plants; you can have no doubt that they are the vessels of that mysterious *Life* which is also in an animal. They are born; they grow and change; they die, leaving behind others like them.

We will get down to the most intimate knowledge possible of the simplest of animals and the simplest of plants, and see what is the innermost hold of this *Life*.

We will look first at an animal which could certainly not be more elemental in its form and in its way of living.

"There is a very tiny animal which is abundant in fresh water; it frequents ponds, pools, etc. This is the *Amœba*, a unicellular animal. You should examine these Amœbæ; you will require to have them arranged under the microscope. I think they will end by fascinating you. Not perhaps at first, for you may regard them as no more attractive than specks of rather dirty jelly. By and by, however, the speck may begin to behave in a way no jelly indulges in. At one point a little swelling presses outwards; the rest of the cell is dragged, or rather flows, after this advance piece; there is another swelling out and another general move onwards; the creature is actually capable of locomotion. Its display may be extended. Slender prominences may push far out like fanciful arms; you may be lucky enough to see two of them bend round and clasp within them a minute atom of some kind which you could almost imagine they had aimed at when they started. It is engulfed; the cell-substance flows round it and the whole returns to the condition of a smooth morsel like a drop of mucus. You could imagine that two hands had reached out, clutched a bit of food and transferred it to a mouth. In effect, that is really what has been done, and you have witnessed the performance of part of one of the vital processes of an organism, namely, feeding as a preliminary to digestion. An amœba will not accept every atom lying within reach; it *chooses* its food.

"You may be more curious now about the nature of the bit of jelly (Fig. 35). You will not find any boundary wall. The substance of the outer region of the cell differs distinctly from that of the centre; the former is clear and transparent, the latter is clouded with numerous granules of various sizes. Somewhere in the granular matter lies a well-defined, much more solid portion of cell-matter. This body, which is rounded in outline, is called the *nucleus* and is of the utmost importance. The cell-substance is called *protoplasm*. Protoplasm must stand out in your mind as being that without which the world would be a dead world. It is that part of an organism which is endowed with *life*; it lies at the heart of the mystery which is life. It has been called 'the physical basis of life.' You will agree then that it was right that I should lead you to think about it. Every living cell in your body is a protoplasmic cell; every living cell or part of a cell in a plant is protoplasmic. This protoplasm is not an element; neither is it a simple chemical compound. It is a very complex substance indeed, and one the nature of which is not yet fathomed. We shall have to leave it now without entering into its chemical constitution.

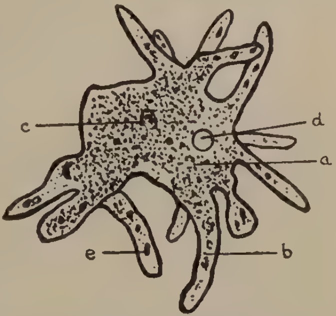

FIG. 35. AMŒBA

a, cytoplasm; *b*, pseudopodium; *c*, nucleus; *d*, contractile vacuole; *e*, food particles.

"The protoplasm of the amœba is in gentle, regular motion; its currents are indicated by the granules which can be seen moving round with the streaming semi-fluid. Similar streams are to be seen in some plant cells. Do you remember that a muscle fibre, i.e. a muscle cell, has the power to alter its length and thickness? The manifestation of the power of protoplasm *to flow* is offered by muscle cell and by amœba cell.

"The food captured by the amœba includes other minute unicellular animals and plants, as well as fragments of algæ. The gradual alteration and absorption of the food, within the protoplasm, has been watched. Any part which cannot be dissolved makes its way in course of time to the surface and is shed off. Thus, this one cell can secure its food, digest it, and throw out its waste.

"The maœba takes in air over its whole surface: the cell which functioned as a stomach also functions as a lung.

"There may come a time in the life of the amœba when its history is carried farther. First, the nucleus divides; then the protoplasm gathers into two masses round the new nuclei; then the two masses separate, and behold, there are two amœbæ in place of one. This is one way of carrying on the race.

"If you now sum up what you have learnt, you will realise that this one cell can carry out every process on which depend the life of the individual and the life of the race.

"It accomplishes:

(*a*) Digestion,
(*b*) Respiration,
(*c*) Excretion,
(*d*) Movement,
(*e*) Reproduction.

"Imagine that after the nuclear division the two new cells did not separate, and that the process of division was repeated with each of them; that this took place again and again; a mass of similar cells would be formed. There are some animals which answer to this description.

"Picture to yourself again that some of the cells in the mass adopted a form differing from that of the rest, and were better fitted to perform some one part of the work than the others. You might call them 'specialist' cells, just as you have 'specialist' teachers. In the higher animals this specialisation or differentiation has proceeded very far. As examples, we may mention nerve cells and muscle cells. Cells are grouped into tissues, e.g. muscular tissue, connective tissue. The cells are the bricks of which the body house is built."[1]

There are a few points to add to the above description. Another term, *cytoplasm*, is applied to the protoplasmic substance exclusive of the granules and the nucleus. Within the cytoplasm a clearly defined space becomes visible, possibly after you have watched a little while. This cavity, or *vacuole*, appears and disappears rhythmically. When it contracts its fluid contents are driven into the cytoplasm.

When conditions become unfavourable, the *Amœba* is able to secrete a rather horny envelope for itself; within this it rests till it is safe to become active again.

As far as we know, *Amœba*, this organism about one-hundredth of an inch in diameter, is the *unit* of living matter, consisting essentially of cytoplasm and a nucleus. All more complicated organisms are multiples of this unit: it is the *cell*.

PLEUROCOCCUS: A UNICELLULAR PLANT

The green smears on the bark of the damper side of a tree-trunk will furnish you with thousands of specimens of this. Mount a morsel in a drop of water for examination under the microscope.

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[1] M. A. Johnstone, *Physiology for Girls*, pp. 48–52.

Again, as in *Amœba*, we have the essence of simplicity allied with perfect performance of every vital function. But this solitary cell is far from being a replica of *Amœba*. To begin with, it is definitely spherical and its outline does not vary (Fig. 36). Then it is green. You must fix your attention well on these two points. The contents of the cell are again protoplasmic. The specialised part of the protoplasm known as the nucleus will come into view if the cell is treated with a staining reagent such as iodine. There is no contractile vacuole, which is another important difference. Starch grains can be identified.

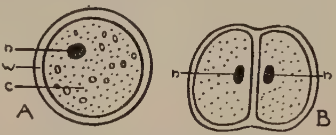

FIG. 36. PLEUROCOCCUS

A, Single-celled plant; B, Plant which has divided into two cells.
c, cytoplasm; *w*, cell-wall; *n*, nucleus.

The cytoplasm of this cell has been able to clothe itself. It has manufactured from its own substance a thin skin of a new kind of material all over its surface; it has enclosed itself within a wall in which there are no doors, and it is this wall which keeps the cell-outline always the same. The new substance is *cellulose*, akin to starch.

The evolution of this casing for the protoplasm held tremendous consequences for this little living thing, and for all the elaborate plant forms of which it is probably the ancestral form. Naked *Amœba* could induce any solid scrap it wanted to enter its body at any point. *No* solid particle can pass through the almost invisible coat of *Pleurococcus*. It has doomed itself to depend on sustenance limited to what can pass through this coat in the form of solutions. And that means, further, that it is doomed to do a great deal more work. That which *Amœba* got ready-made as food, it must make from the gases and salts which enter as solutions. It must take simple substances and from them manufacture sugars and proteins. Some pages farther on you will learn that the energy it needs it gets from sunlight, and also that in order to lay hold of that energy, as it were, there must be present a green substance known as *chlorophyll*. This *is* present in *Pleurococcus*. The state in which it exists in cells will be more easily seen in other plants; with some difficulty you may make out in this solitary green cell a more substantial-looking spot in the cytoplasm which carries the green colour; it is called the *chloroplastid*.

The presence of a membrane limiting the protoplasm, and the associated occurrence of chlorophyll, form the two most constant differences between a plant cell and an animal cell, as also between multicellular plants and multicellular animals. There are exceptions on both sides, but they need not concern us at this stage.

Pleurococcus multiplies somewhat similarly to *Amœba*. The nucleus divides into two, and the cytoplasm follows suit; this is followed by a second division of the two new units; a wall is secreted round each of the four. Under your microscope you may recognise cell groups of two or four. *Pleurococcus* can also go into a resting state within a thickened wall when water or food is scarce; it is ready to revive in time of plenty.

This little cell possesses two names—either *Pleurococcus vulgaris* or *Protococcus viridis*.

CHLAMYDOMONAS: A MOTILE PLANT

This is a still smaller plant than *Pleurococcus*; its name seems most unfitting. Water which has been standing for some time in a rain-tub may have a green scum on the surface which is composed of *Chlamydomonas* in masses (Fig. 37).

This one-celled plant is oval. There is a cell-wall as usual. The cytoplasm is interrupted at the upper end by a flask-shaped cavity in which lies the nucleus. Chlorophyll is present, and there is also a mass of protein substance (a *pyrenoid*). The most unusual feature is a speck of pigment, the "eye-spot," which is said to be able to judge of the direction in which light is coming. But the astonishing thing to find in a plant is a pair of thread-like outgrowths (*flagella*) from the cytoplasm which extend far outside the cell at its narrower end. They are in constant vibration in the water, and the rhythmic character of the movement results in progression. This plant actually moves from place to place.

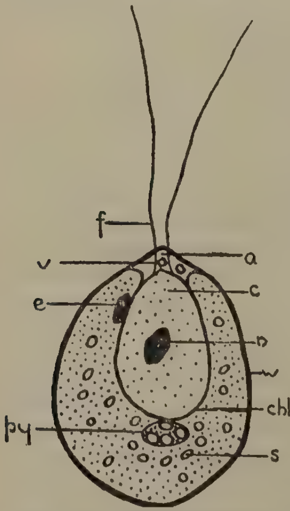

FIG. 37. CHLAMYDOMONAS

a, anterior end; *c*, colourless cytoplasm; *chl*, cup-shaped chloroplast surrounding *c*; *n*, nucleus; *py*, pyrenoid; *s*, starch, most abundant round *py*; *v*, contractile vacuole; *w*, cellulose cell-wall; *e*, eye-spot, position somewhat variable; *f*, flagellum.

Many scientists believe that during a time when the earth was young there existed on it no living things any more elaborate than those we have been considering. They think, too, that life was confined to the waters, that some of the organisms drifted hither and thither on the currents, whilst others steered a way of their own by their waving flagella. The next stage may have been that in which plants became attached to some object and stayed there, as the Seaweeds do to-day. Then life spread to the land, and plants became fixed and truly rooted there.

One cell can be a perfect plant, and the cell is the unit from which every plant is built up. Between the unicellular beginning and massive plant bodies made up of millions of cells and exhibiting endless variations there are plenty of intermediate forms which point to the ways along which the evolving races of plants and animals travelled.

Myxomycetes: a Many-Celled Animal

Let us think again of *Amœba*, and imagine that thousands of *Amœbæ* have flowed together into a jelly-like mass—their cytoplasms mingling, but their nuclei remaining distinct. There really exists an organism essentially like that—several species of it, in fact. They are known as Slime-fungi or *Myxomycetes*. You might search for them in damp weather in damp places, such as rotting tree-stumps. They are very queer. It is difficult to say whether they are plants or animals, but at present they are classed with the latter. For days they may behave like a gigantic *Amœba*: they possess a contractile vacuole; they take in, digest and reject solid bodies as *Amœba* does. The nuclei multiply by division. There is a perpetual streaming movement within the protoplasm; the mass moves as you saw *Amœba* do, by pushing forward portions of its substance and dragging the rest after it. At first it is disconcerting to arrive in the morning and find that the filmy stuff which you had left on one side of a saucer has crept to the other. Then you try it with inducements like water and find that it may follow it. These particulars would lead you to agree with the idea that this thing is an animal, like *Amœba*. But there is another phase in its history. One day it begins to avoid water and may seek darkness. The soft, shapeless sheet of protoplasm gathers itself together at various points and breaks up into a number of piles. These take shape as firm, hard-walled cases, seated on stalks. These cases are filled with spores (cf. p. 286). Every species has its own peculiar kind of case and spore, and extremely beautiful little objects some of them are; they vary in size, but many are about the size of a pin-head; they are yellow, bright red, etc. There is no gainsaying the resemblance of spores and spore-cases to counterparts in plants.

The spore-cases rest for a period, then they break down and the spores come out. Each spore is enclosed in a membrane. When this opens there emerges a naked bit of protoplasm, which sets off gaily through the water which of necessity was present, oaring itself along by its one flagellum as does *Chlamydomonas* with its two. Later the thread of protoplasm is withdrawn, and the creature looks a mere *Amœba*. Swarms of these fuse, and *there* is a Myxie!

The points to note are these: (1) At one stage there is a multinucleate body, though it would not be correct to say a multi-celled body; (2) that throughout the reproduction phase of its life its affinities seem to be with plants.

SPIROGYRA: A MANY-CELLED PLANT

Some of the green scum which gathers on a pond in summer may be a simple Alga called *Spirogyra*. It is very easy to examine and to understand (Fig. 38). Each bit consists of a chain of cells joined end to end. The cell shape has changed from globular to rectangular. Cellulose cell-walls enclose the protoplasm. The latter no longer occupies the whole space, but spreads itself as a lining over the walls, whilst strands of it stretch across from side to side. The impression given is that the increase in the amount of protoplasm has not kept pace with the extension of the walls (Fig. 39). There is no contractile vacuole, but many vacuolar cavities containing sap. A nucleus is present. The most striking bodies are the chloroplastids. It is usual for these to be numerous and simple in shape: oval, plate-like, etc.; *Spirogyra* is unique in having spiral chloroplasts which (one to ten or so in number) lie within the cytoplasmic lining of the cell. Attached to them here and there are minute bodies which must be carefully noted; they are the *pyrenoids*,

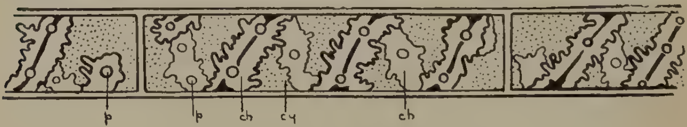

FIG. 38. SPIROGYRA
ch, chloroplast; *cy*, cytoplasm; *p*, pyrenoid.

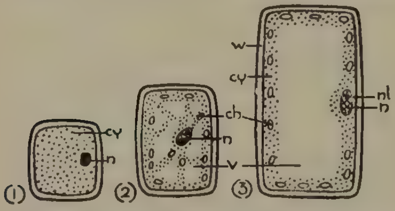

FIG. 39. STAGES IN DEVELOPMENT OF CELL
(1) Cell filled with granular cytoplasm; (2) Cell with many vacuolar spaces; strands of cytoplasm; (3) Cytoplasm arranged as lining for cell-wall.
w, cell-wall; *cy*, cytoplasm; *n*, nucleus; *nl*, nucleolus; *v*, vacuole; *ch*, chloroplast.

morsels of protein; round them lie grains of starch. The protoplasm of *Spirogyra* shows streaming movements.

In this plant cells have reached a more diversified character, and there is a great advance in that they are living together as a many-celled organism, and on occasion they act together (p. 294). Nevertheless, they are still cells every one of which resembles its neighbour and functions like its neighbour. The massing of incalculable numbers of cells which are specialised to fulfil special functions (as in a tree), will be studied in Chapter XVI.

CHAPTER IX

THE MAINTENANCE OF THE PLANT CELL

(*a*) How Water and Salts enter the Plant Cell

The protoplasm of the cell held much water in its substance, and the vacuole or vacuoles are filled with watery sap. In trying to find out how the water got there, we must explain its passage not only through the cellulose wall of the cell, but through the thin layer of protoplasm which is pressed close to the wall like a lining (Fig. 39). Such a layer is the position taken up by the cytoplasm of an adult cell in plants higher than the unicellular. The observed facts pertaining to the absorption of water are well known, and to these we shall have to confine ourselves, for the ultimate theories are too difficult and debatable for this stage of botanical study.

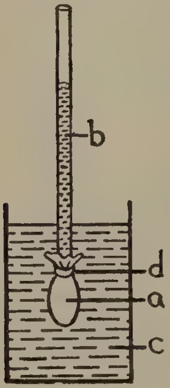

Fig. 40. Osmoscope

a, parchment cup; *b*, glass tube; *c*, dish of pure water; *d*, attachment of cup. *a* and *b* contain sugar solution.

We may begin with an experiment which tries to make an imitation unicellular plant, and to set it working (Fig. 40). You need a parchment cup *a* to stand for the cell. Fasten this very securely with waxed thread to a glass tube *b* open at both ends, and immerse it in a dish of pure water *c*. The cell cavity includes both *a* and *b* and, as it now stands, it differs from the cell in that it is not closed at every point. Fill the cup and a very short length of the tube with a five per cent sugar solution. Then watch what happens, and it will show all the more quickly if the tube is narrow. Without any apparent force which makes it do it, the solution in the tube mounts upwards, to a height of perhaps several feet, giving evidence of a pressure three or four times that of the atmosphere. Water must have entered the cup. To begin with, there was water on both sides of the parchment membrane; why was the water movement in one direction only? One concludes that it was because of the presence of the sugar on one side only, and of the fact that any given volume of the sugar solution contains fewer molecules of water than an equal volume of the pure water. It is a law of physics that in such conditions molecules tend to move or *diffuse* from the place where they are most concentrated to any available place where they are more sparse; there is a perpetual striving after a uniform level. If nothing happened to prevent it, the movement in the experiment would go on until molecular water equilibrium was established; at this point the solution in the tube would cease to rise. Seeing that water could pass through the parchment, it is a membrane *permeable* in respect to water.

A mass of water has been pushed up a considerable distance—that is, the force of gravity has been overcome. Another force must have done this. What force? The name of *osmotic force* has been given to it, but this is not in itself enlightening, and it is not easy to make it clearer in a few sentences. Perhaps you may regard it as the force resident in the water molecules as they perpetually vibrate (or electrically repel one another), and in their vibrations move outwards into spaces of more freedom from their own crowds—in this case, through the parchment wall.

Let the experiment now be repeated, the completely closed cell being imitated by using a very short tube and closing the end of it. Water again passes inwards. The pressure of this incoming water—the *osmotic pressure*—is now employed, not in raising a weight of water, but in distending the parchment cup. If the wall were strong enough, this internal pressure would increase until equilibrium was established between the water inside and the water outside the membrane. In ordinary apparatus the parchment tears or is dragged off the tube before this point is reached.

If the sugar solution were in the outer vessel, the parchment cell would collapse, because the pressure and the consequent movement of the water molecules would be outwards—that is, the parchment permits of reversal of direction in movement.

What are the sugar molecules doing meanwhile? Are they, according to law, trying to equalise their distribution within the two liquids, by way of the membrane? They are, and, in doing so, are exerting *their* osmotic pressure on the cell wall. Whether they get through or not depends on the nature of the membrane. If they succeed, it is because the membrane is permeable to them as well as to water. If they do not, and no trace of sugar appears in the outer vessel, then that particular membrane is *semi-permeable*—that is, lets water molecules through but refuses passage to molecules of a dissolved substance. Such types of membrane are of paramount importance in the plant tissues, hence it is necessary to know what is their nature.

The particular membrane used in the experimental cell may be permeable to sugar, yet not allow sugar to pass as freely as water. In such a case the internal pressures will rise as before very rapidly, but after a time traces of sugar will appear outside the cell and will grow stronger.

Everything that has been said as regards a solution of—say—sugar on one side of a membrane and water on the other, is equally true of the case in which a strong solution of sugar is on the one side and a weak solution on the other. If the membrane is permeable to sugar, sugar will pass from the strong to the weak solution until the two osmotic pressures are equal. If not, the equalisation will be brought about by the passage of water into the strong solution.

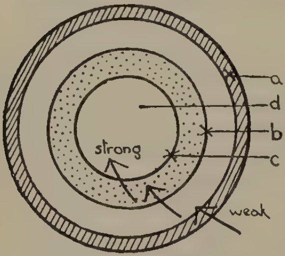

FIG. 41. OSMOTIC CONDITIONS IN A PLANT-CELL; HIGHLY CONVENTIONALISED

a, cellulose cell-wall; *b*, external surface of the cytoplasm, here shown as separated from *a*, with which it is in contact in the living cell; *c*, the surface of the cytoplasm which bounds *d*; *d*, cell-vacuole.

If the solution outside the cell is weaker than that within the cell, water passes as shown by the arrows.

These experiments illustrate the processes in *Pleurococcus*, in the cells of *Spirogyra*, and in the cells of higher plants. Substances, in order to get into, or out of, these cells, must be in a state of solution, and must be able to pass through three membranes (Fig. 41). (1) Externally, there is the cellulose cell-wall. (2) Lying close against this wall is the sheet of protoplasm, and the outer surface of this protoplasm functions as the next barrier. (3) The internal boundary of the protoplasm is also the boundary of the vacuole or vacuoles: this is the third limiting membrane. The cell sap in the vacuole is a watery solution of various chemicals; it was represented by the sugar solution in the experiment.

The first membrane in the cell is a permeable one; the other two are semi-permeable, but they differ from the parchment in that their permeability varies from time to time; a figurative way of expressing the power of protoplasmic membranes is to say that they " choose " what is to pass.

Pleurococcus and *Spirogyra* live in aqueous solutions of various salts. From these they can obtain by this diffusion process what they need to maintain their cell sap at the strength beneficial to them.

What is true for the unicellular plant is equally true for every living cell amongst the millions which make up a great plant, whether they be in contact with soil or only with one another. Their mutual osmotic relationships will be treated on pages 261-70. Meanwhile, single cells may be taken from plant tissue and tested; coloured cells show best what is happening. Remove some of the dark-red cells which occur in the outer layers of the flesh of a ripe Privet berry and mount them in water on a glass slip for the microscope; the cells in the epidermis of Rhubarb stalk may be easier to obtain. By means of a strip of blotting-paper draw under the cover-slip a five per cent solution of common salt, displacing all the water. Probably most of the cells collapse; water has left them to enter the solution outside, which must have been stronger than that inside. In some cells there may be seen a shrinking away from the cellulose wall of the protoplasmic lining carrying its enclosed red sap. No colouring matter passes out; for that, the two inner membranes are impermeable. A cell thus deprived of water is said to be *plasmolysed*.

The experiment may be reversed by flooding out the salt solution from under the slip and bathing the cells again in pure water. They fill out owing to the entrance of water into the now relatively strong solution in the cell-vacuoles. The protoplasmic bag distends till it touches the cell-wall again, and the latter in turn is pressed outwards and gets rid of its wrinkles. The internal osmotic pressure, like that in the parchment cell, stretches the cellulose wall as far as it will stretch; such a cell is said to be in a tense, or *turgid*, condition. When all the cells of a plant are in this state of *turgescence*, the tissues are firm and strong. When the osmotic pressures are low, the tissues appear limp and wilted. The withdrawal of water may be due to evaporation. All this will be seen to be of supreme importance in the plant's vital processes.

Modify the experiment on the Rhubarb cells by immersing them in alcohol. This time the red sap does come out of them. This is because the protoplasm has been killed; its impermeability to the cell salts was a property of its *life*. On a big scale, this is seen in the cooking of Beetroot. The cook takes care not to break into the tissues of the roots; otherwise the red colouring matter will flow into the cooking water. In this case the cells are killed by heat.

(*b*) THE SOURCE OF PLANT ENERGY: PHOTOSYNTHESIS

For the moment we will think only of the simple plants of the preceding pages. Do they need energy? An animal's need for energy is obvious; the energy of a plant which can force apart hard soil to raise itself is not to be doubted. But is this " energy " a need so fundamental as to reside in a *Pleurococcus* or a *Chlamydomonas*? It certainly is. The latter, for part of its life, lashes a way through water; both grow and divide, new substance being made and the bulk of the body extended; that needs energy. Where do these super-simple things get it? Two physiological processes are being carried on in the laboratory of each of these cells, and these processes are virtually the same in the most elaborate green plant. It is very necessary to grasp what is happening in them. A great effort must be made to visualise what can never be seen. Make sure of every step.

Within the cell substance are to be found protein, sugar, starch. All of them contain carbon, and it is upon the carbon you must fix your attention. Throughout the following paragraphs, the carbon of sugar will be made the basis of the changes; the other carbons are probably involved in the same way, but as they can all be traced back to sugar they need not be referred to further. To demonstrate the presence of carbon, heat a little starch (or sugar) in a dry test-tube over a Bunsen flame. It is reduced to a black mass of carbon, whilst some of the water vapour given off is deposited on the sides of the test-tube.

The formula for one sugar is $C_6H_{12}O_6$. How was that substance made? You notice that the hydrogen and oxygen are in the same proportion as in water; for the moment, regard the sugar as being carbon plus water. *Pleurococcus* can get all the water it wants from that in which it is immersed; the carbon for its sugar-making it must get from the air, which, as your lessons in chemistry have taught you, contains carbon dioxide, CO_2. This gas, quite incapable as such of supporting life, is really one of the ultimate sources of all plant and animal matter. By the process of diffusion, the gas CO_2 passes in a perpetual stream (in light) through the cell envelopes of *Pleurococcus* into the interior; as it is perpetually being used up there, the tendency to inward diffusion is maintained.

We inquire next what happens to the CO_2. It is a very stable compound and force will have to do work before the carbon can be split away from the oxygen, to which it is held by the force of chemical affinity. Here enters the power, the energy of the sun; and here, the cell hides from us a vital part of its doings. The sun-energy does nothing to the CO_2 unless chlorophyll is present. The suggestion has been hazarded that the chlorophyll transforms the energy of sunlight into electrical energy. It may be so, but it is not proved.

The great fact upon which we can depend is that the sun-energy does force apart the carbon and oxygen of carbon dioxide. Energy is *never* destroyed or lost, and the sun-energy in doing this work merely changes its form and becomes resident as *latent* or *potential* energy in the atoms of carbon and oxygen. These two elements have strong chemical attraction for each other, and whilst they are apart this unsatisfied tendency to come together is a form of energy. The case of a boulder poised on a slope and then set rolling down it is a parallel; the attracting force is gravity acting between the boulder and the centre of the earth; at a height the boulder possessed *potential* energy, which, when it moved, was translated into *kinetic* energy.

So the carbon and the oxygen in the green plant cell might have a future in which they could come together again, and then there would be a chance of their potential energy showing itself in another form. Let us see what happens to them. Much of the oxygen diffuses out of the cell, because its pressure within the cell is always growing. The carbon unites with the constituents of water in the cell in such proportions that sugar is formed. So what energy the carbon possesses in respect of oxygen is retained within the cell. The great fact—A—is thus established: *Every molecule oj sugar is a storage-place of the energy which the green cell has won from the sun.* It does not matter how many changes it may have to undergo, this is *the* source of the energy of plants.

The equation which gives the bare final results of the process is this:

$$6CO_2+6H_2O=C_6H_{12}O_6+6O_2.$$

Notice that it is the "final result"; quite probably the whole affair has been carried out by several progressive changes. This great phenomenon in the plant's life is called *photosynthesis* or *carbon assimilation.* It involves the absorption of carbon dioxide and the release of oxygen.

We see the energy now held in the sugar (or starch, or protein) molecule; it must be set free for use. At first sight, what happens seems contradictory to what we have just arrived at. One of our experiments with germinating seeds (p. 12) proved that they must have oxygen, that they respire in the same sense that an animal does; they take in oxygen and give out carbon dioxide. This is the very reverse of the photosynthetic process. This respiratory oxygen diffuses into the plant cell. Its attractive force is felt by the atoms of carbon within the sugar; it is strong enough to withdraw them. Then carbon and oxygen unite. This union of carbon and oxygen is an instance of *oxidation:* it is *respiration.* When it is accomplished the chemical attraction between the two elements is satisfied, and the potential energy which was latent in them is, as a result, liberated. This brings us to the second great fact—B: *Respiration makes available for the plant's needs the energy which had been stored up.*

Put statements A and B together and you have a summary of the energy situation within the plant.

The plant uses its energy for growth, for movements, and also as heat, although the last is usually unnoticed because it is dissipated so quickly from the extensive surface of the plant. The oxidation process in the plant cell is the counterpart, at low temperatures and at a slow rate, of the combustion of carbon and oxygen in a fire. It is identical with what occurs in an animal cell, where it is the animal's respiratory act.

There is room for error in any interpretation which we can put upon what goes on in the plant cell. There is room for confusion in trying to picture the two processes with their contradictory results going on together. We may understand better if we try to remember three facts: (1) The amount of oxygen given out in photosynthesis is much greater than the amount of carbon dioxide given out in respiration; the average proportions in an active green leaf may be as twelve to one. (2) Photosynthesis is restricted to hours of light; respiration is always going on. (3) In full daylight, the respiratory CO_2 does not leave the cell; it is used up as photosynthetic CO_2. Neither does all the photosynthetic oxygen leave the cell; it is used up as respiratory oxygen. At a certain stage in light intensity, the one process uses up and finds sufficient the by-product of the other process. For example, at certain times, shortly after sunrise and before sunset, there is no movement of CO_2 into the cell, or of oxygen out of the cell.

ANAEROBIC RESPIRATION: THE YEAST PLANT

Yeast is a one-celled plant. It illustrates in the simplest form plants in which there is no chlorophyll; its mode of respiration is peculiar.

Form of the Yeast Cell. Place a small piece of German Yeast in a dish with some warm water; stir till it crumbles down; separate off the water; a creamy residue is left in the dish. Put a smear of this under the high power of the microscope and examine it. You might imagine that you had got a crowd of excessively small, rather distorted, anæmic *Pleurococci*. Each individual is ovoid. There is a cell-wall; within the cytoplasm are granules, a nucleus, and a vacuole. The wall is not of cellulose, but of a gelatinous-like substance. The outstanding facts are the absence of chloroplastids and the absence of starch. If the iodine test for starch is applied, some of the granules turn orange-red; they are *glycogen*, stored much as it accumulates in the liver of animals. Some of the rounded bodies are oil globules, which is another form in which food may be kept in a plant cell for a long time.

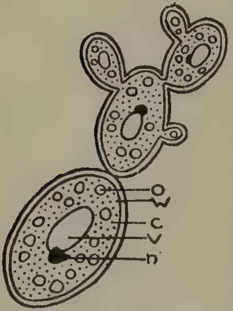

FIG. 42. YEAST CELLS, BUDDING

w, cell-wall; *c*, cytoplasm; *n*, nucleus; *o*, oil globules; *v*, vacuole.

When Yeast is well-fed it multiplies at an extraordinary rate and in a very simple way. The wall bulges at one spot, the cytoplasm follows the bulge; the nucleus of the cell divides into two, and one of them moves into the "bud," which is rapidly converted into another oval cell. In the meanwhile the bud may have become a parent (Fig. 42). For a time the cells may remain connected, new ones budding out freely; at this stage it reminds one of the cell filaments in *Spirogyra*. The string of cells ultimately breaks up, and the process is at an end.

Mode of Living. For Yeast the same law of respiration as for the green plants operates—that is, it must have regular supplies of oxygen, and it gives out carbon dioxide. But it does not take its oxygen direct from air; or, rather, it can get oxygen from another source if air is not available. When Yeast is grown in sugar solution in a closed flask, the liquid froths up when shaken. The froth bubbles are filled with carbon dioxide, which may be drawn off by a delivery tube into limewater. The usual carbon dioxide reaction is seen in the formation of calcium carbonate. Sugar disappears from the liquid in the flask, and alcohol appears; the sour smell suggests this.

This is a point which needs concentrated attention. What has happened in the flask is expressed by the equation:

$$\underset{\text{Sugar}}{C_6H_{12}O_6} = 2CO_2 + \underset{\text{Alcohol}}{2C_2H_5OH}.$$

The sugar molecule has been broken up, and molecules of carbon dioxide and alcohol have formed. The hydrogen in the sugar has, as it were, been compelled to give up the oxygen, and the latter has at once gone to join the carbon, in close union. As in the green cell, the result of this oxidation is CO_2, and the latent energy of the carbon and oxygen is put at the disposal of the cell. Some of the sugar it also uses as material for building up its protoplasm. There are by-products, such as glycerin, which we need not think of now. This way of obtaining oxygen and energy is more difficult than that in which the plant takes oxygen straight from the atmosphere. What breaks down the sugar? Here we are faced with one of the inner mysteries of living things, and this mystery permeates all the vital processes of plants and animals. In those wonderful laboratories called "cells," starch may be changed into sugar, one sugar may be changed into another, and so on. How is it done, and what does it? We say that it is done by an agent called a *ferment* or *enzyme*; nobody has ever seen one of these—we see only the results of their actions. They set going great conversions of substances, but at the end of the operation they themselves are practically as they were at the beginning. We shall meet with them again and again, and probably remain, like others, baffled about their personality and hidden ways. In Yeast we have a single plant cell within which an enzyme has experimented on sugar and produced carbon dioxide and alcohol. The scientist has named this particular ferment *zymase*.

By grinding them very fine the Yeast cells can be killed. If the juice extracted from the powdered remains is given an opportunity of inducing fermentation in sugar, it will do so. Clearly, the power of the enzyme is not dependent on its association with living protoplasm.

What is a customary course in Yeast may occur under certain abnormal conditions in higher plants. For instance, an experiment may be arranged whereby the supply of external oxygen is entirely cut off from germinating peas. Yet germination may go on for a little; the energy necessary for it is derived from the breaking up of the seed's own tissues, from its starch and protein, the chief end-products being carbon dioxide and alcohol.

The form of respiration which is independent (except indirectly) of the oxygen of the air is called *anaerobic*; the normal, direct from air, is *aerobic*.

The fermenting action of Yeast is seen when it is used in baking bread. The Yeast is mixed first with a little sweetened warm water to give it a start; then it is stirred into the dough. The starch of the flour is changed into sugar, and this the Yeast changes further. The carbon dioxide liberated forms bubbles within the dough and makes it "rise"; the small amount of alcohol evaporates. This is the work of one species of Yeast; there are others.

When food and water are scarce, Yeast cells can transform their substance into *spores* having thickened walls. So, they can rest until conditions become possible for activity. So, too, they can float in myriads in the air. The Yeast plant which causes fermentation in wine is carried in this way to the fruits in the fields. Fermentation of germinating barley grains, brought about by Yeast, produces beer. The amount of alcohol in these fermentation beverages is never more than about ten per cent, for if any more is present the Yeast cells are killed by it.

CHAPTER X

THE LIFE-HISTORY OF WHEAT

Triticum vulgare

THE generic name is derived from the Latin *tritus*, rubbed; the early wheat-users rubbed their grain free from the husks.

Man and Wheat have travelled so long in company that a student may well be curious about the plant's ancient history. It must have been a very primitive man indeed who found the wild grass which bore seeds which he found good to eat, and who sowed it near his dwelling. Even in the Neolithic lake dwellings in Switzerland five small-grained varieties of Wheat have been found, and almost certainly these had been improved by man's cultivation. The closest modern relative of this estimable plant is the ill-famed Couch Grass. The original wild stock from which it sprang is not known for certain; Mesopotamia has been suggested as its first home, and, more recently, it has been claimed that a wild Wheat found near Mount Hermon is the ancestor.

Man's first religious ideas were inspired by the earth and its vegetation. It was from the crude fundamentals of a beneficent god or goddess of nature that there were evolved the complex religious cults of Egypt, Greece and Rome. In all of them, grain—and especially Wheat—played an essential rôle. The cult of Osiris, the ancient god of Egypt, embodied the principle of the annual death and the annual resurrection of the Spirit of vegetation. According to the myth, Osiris, son of the earth-god Qeb, took up his abode on earth as king of the Egyptians. His wife, Isis, having found Wheat and Barley growing wild, the god gave them as food-gifts to his people. A jealous brother murdered Osiris and took elaborate pains to put his body beyond reach of recovery by tearing it into fourteen pieces, which he flung to the far corners of the land. Searching untiringly Isis found them and buried them, each in its place of discovery; in all these spots arose a new shrine of worship. Here was an example of the vegetation religious cycle—the kindly god, his violent death, the scattering of his body, the resurrected god in his new temples.

The Egyptians of 4000 B.C. depended mainly on the cereals for food. One of the most curious discoveries of recent archæological research was that made in examining the bodies of Proto-Egyptians, which for six thousand years had rested in the sands of Egypt. In the stomachs of these bodies could be detected the remains of the last meal eaten, and in nearly every case husks of Barley and Millet were identified.

Pliny has many interesting things to say about Wheat. He tells a tale of Sextus Pompeius: "Sitting on a time before his barn-doors to see his corn winnowed, he was suddenly taken with a fit of gout, and whether by chance or in a rage for the extremity of the pain, he thrust his legs above the knees into a heap of Wheat lying thereby. Finding his legs mightily dried thereby, and himself wonderfully eased of his pain, he never used any other remedy afterwards." He states that the value of any Wheat was known by the weight of it assigned to wrestlers; Italian held the first place. He expresses disapproval of the practice of making bread with sea-water in order to economise in salt.

Coming down to the days of the herbalists we find Dodoens advocating the healing power of raw Wheat, which, after being chewed in the mouth, is laid on the wound caused by the bite of a mad dog.

Wheat, the main food of mankind, has naturally been the subject of many experiments in agriculture, performed with a view to raising new varieties or of testing the suitability of varieties to different soils. There are two main lines of experimental research and one less dependable line.

(*a*) By the first method, "seminal sports" (or "seminal varieties," which are less pronounced than "sports") are selected from amongst the seedlings of a species, and cultivated with special precautions for several successive generations. Mr. Patrick Sheriff of Haddington (1791–1876) was an early and very successful raiser of new varieties of cereals—mainly by this method of variation and selection. He searched his cornfields for plants showing modifications which were in some respect or other of value, and cultivated stock from these. Unless the variations were transmitted in an unbroken line, they were, of course, of no use. By repeated sowings, and elimination of all offspring which did not reproduce the characters concerned, the variety became "fixed" and "came true" from seed. Several years of selective cultivation might be necessary to secure the fixation of a new variety.

(*b*) Variations may be induced in plants by hybridisation. This plan was also tried by Sheriff and apparently with satisfactory results. Two grains are selected, one of which is strong in a certain desirable quality, and the other in a second desirable quality. By crossing these two an attempt is made to get new plants in which the two qualities will be combined. The breeder must carry the experiment to such a stage that he makes sure that the new variety will breed true. " Crossing " is done by transferring the pollen of one parent to the stigma of the other, care being taken that the latter does not get pollen from any other source.

(*c*) Changes in a plant may be responses to a change in environment (e.g. water-supply, illumination). It is still doubted by many that such " acquired " characters are transmitted to succeeding generations. However, evidence seems to be gathering in favour of the positive view.

The breeder of new Wheats aims at getting an ideal combination of well-balanced valuable characters—good colour, the " strength " which the baker asks for, heavy crops of grain and good straw, immunity from diseases such as "rust" (p. 297). He may be seeking a Wheat suited to special cultivation conditions; some Wheats are adapted to poor soils on hill-slopes; some behave better as spring- than as autumn-sown crops; some are excellent in warm climates but failures in a colder land. The most important species as far as Europe, Australia and America are concerned is Common Wheat, *Triticum vulgare*, in its many modified forms.

Patrick Sheriff, the pioneer breeder of cereals, on his quiet farm in Scotland, is connected through a long line of workers with the organised research of to-day. One of the most famous Wheats evolved in this great quest has a history which illustrates very well the methods employed and the far-reaching triumph and usefulness of the discovery. It is the story of the *Marquis* Wheat.

A Canadian Wheat must ripen early; otherwise it may be ruined by early autumn frosts, or by the wet and " rust " which autumn brings. *Red Fife* was long the standard variety most favoured in Canada, but even that was often frozen in the fields, and the matter was a serious one. Dr. William Saunders, a Government agricultural official, and his two sons, worked at it for a long time. Wheats were imported from Arctic Russia, from hill stations (up to eleven thousand feet) on the Indian Himalayas and from similar situations. Many hundreds of new varieties appeared as the result of natural and experimental cross-pollination, but for a long time no satisfaction was obtained. Ultimately, one of the sons, Dr. Charles E. Saunders, was made " Cerealist for Canada," and was enabled to devote the whole of his time to highly specialised work. He re-examined all the varieties which cross-breeding had brought into existence, and at last discovered one in which he saw possibilities; he called it *Marquis*. It had arisen from a cross made between *Red Fife* as the male parent, and an early Indian Wheat, *Hard Red Calcutta*, as the female. The Indian Wheat was a trade mixture of types, not a pure strain, and further breeding and eliminating had to be done in order to get a stable variety; this involved endless care and patience. The reward was the *Marquis*. "At first there were only a few grains of the precious *Marquis*, all obtained from a single head picked by Dr. Charles E. Saunders in the summer of 1903; but how great were their potentialities. These grains were planted out in the spring of 1904 in a tiny plot in the experimental garden. Soon they began to sprout, and at length there was a small patch of green containing twelve plants in all. In August the little harvest was reaped. The yield was much less than a single pound of grain; and the first crop of wheat that was destined within a dozen years to overtax the mightiest elevators in the land, was stored away in the winter of 1904–5 in a paper packet no larger than an envelope."[1]

Marquis ripened before most of the common Wheats, and gave an excellent yield. They went on to test its acceptability to the miller and the baker. Evidently no big-scale test could be carried out with such precious grain, and indeed Dr. Saunders had at that date neither milling nor baking facilities in his laboratory. However, he tried another way—simple and curious: he chewed the grain! The starch was changed into sugar and removed; the gluten remained in the mouth as a sticky mass. The Wheat tester becomes expert in judging from the fine pale colour of such a mass what colour of bread it will work up into, and from its degree of elasticity the size of loaf which it will give. Dr. Saunders chewed his wheat, and regarded the results with much satisfaction. From 1904 to 1906 he sowed and gathered. By that time he had made his arrangements for milling and baking, and at last he turned out, with success full of promise, his first loaves. In 1907 seed was put in on a farming scale, and in 1909 seed was distributed to the public—first in the Dominion, shortly after in the United States. Now it forms one of the chief Wheats in every great Wheat-growing country in the world.

In character the new Wheat was not only early and prolific, but its dark red grains were plump and heavy, hard with gluten. Its growing period on the Great Plains is 115 days, or three or four days less than the older *Fife* varieties—which, of course, means more in Canada than in the States. Its baking strength is high; this decides the size of the loaf, and is related to the varying proportions of the two proteins which compose the gluten.

But already, in 1927, *Marquis* is being outrivalled. The new *Garnet* wheat ripens ten days earlier than *Marquis*, yields whiter flour, gives greater weight of grain and has equally good milling qualities. It is claimed that regions one hundred miles above the present grain belt will be opened to settlement and cultivation—forty million acres of virgin land. It is a triumph of applied botanical science which almost surpasses imagination.

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[1] A. H. R. Buller, *Essays on Wheat*.

British research is not ignoring Wheat, though the scale is not so enormous as in America. It has made great advance. The system is based on the laws of inheritance of plant characters, as known. The demonstration of these laws in the experimental results is wonderful; it *is* wonderful to be able to predict truly from microscopic examination of the nuclei of fusing germ cells, whether or not the Wheats which are being "crossed" will yield seed which, in its turn, will be fertile. Two new forms of Wheat have lately been marketed by the Cambridge Breeding Institute; *Yeoman II.* has higher baking and milling qualities than *Yeoman I.* had; *Cambridge Browick* has stiff straw and gives heavy crops.

A Grain of Wheat: Its Germination

It is a dullish-looking object to carry so much significance. Its shape is a longish oval, deeply grooved down one side; it is tipped with a brush of short hairs, and marked at the opposite end by the scar of detachment from the fruit-stalk. Near the scar is a wrinkled spot about two millimetres in diameter. When the expert is selecting his grain he looks at several characters —there should be uniformity amongst the grains in the sample; each should be plump and have a bright, smooth coat; when cut across they should look translucent; the wrinkled patch should be distinct.

A grain of wheat looks like a seed but it is a fruit; this will have to be verified by watching fruits develop. Sketch grains, of course, in their dry state. Soak some for a day in water; they are then softer and easier to manipulate. With them may be compared a larger grain—that of Maize, of which the structure and the history are much the same. Fruit-coat and seed-coat are so completely fused that you will not be able to separate them when you strip off the covering of the grain. The naked seed is a hard white mass, featureless except for the wrinkled spot. This is the vital part, the embryo. Revive your memory of (*a*) the embryo in the Bean, which occupied the whole seed, and which, in growing, used food packed within its own body, in the two plump cotyledons; and of (*b*) that in the Bluebell, which was very small, which maintained its growth for a long time on the endosperm, a food-stock lying outside the embryo—the starch food being brought out of the stores by the specialised tip of the single cotyledon; and of (*c*) the poor little embryo of the Lesser Celandine, which seemed to have such a bad start in life, but whose one cotyledon became a good green leaf.

Dissect out the Wheat embryo carefully with needles (Fig. 43). Quite distinct is the plumule, with its rudimentary leaves fitted nicely round each other, and hiding in the centre of them the bare round growing point. In line with the leaf-bundle is the pointed radicle. It is impossible to distinguish a hypocotyl. You will ask if there is any cotyledon here at all. Get a sectional side view of the embryo so as to include its line of contact with the main white mass. You will find that about the region where plumule passes over into radicle there is an outgrowth from the embryo which assumes the shape of a flat plate of tissue and spreads over a small area of the white substance; hence, when you look straight at the embryo in its place in the seed, you see it resting on this expansion of itself as on a thin cushion. The name assigned to this plate of embryonic tissue is the *scutellum*, or shield, though why an infant plant should be given a shield as a resting-place I do not know.

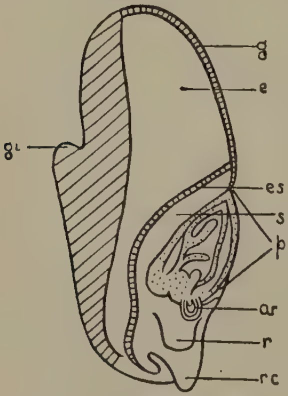

Fig. 43. Wheat-Grain

g, grain coat; *gi*, infold of *g*; *p*, plumule; *r*, radicle; *rc*, root-collar; *ar*, adventitious root; *e*, endosperm; *s*, scutellum; *es*, epithelium of *s*.

By this time, you no doubt suspect the white bulk of being endosperm. If you test it with iodine you find that it gives a dark-blue (nearly black) starch reaction, whilst the embryo itself responds by turning brown. The scutellum is the puzzle. A commonly accepted view is that it is the plant's one cotyledon, and that, like the tip of the Bluebell cotyledon, its function is to absorb food from the endosperm cells and pass it on to the embryo as it grows. This seems reasonable.

Examine the radicle, the root-cap of which is well defined. It is surrounded by a covering sheet of tissue which has no parallel in the other seeds you know. The name which has been given to it is *root-collar* or *root-sheath*. Can you find out what purpose it serves, and what its relationships are? Is it an extension of the scutellum, or is it an independent new thing?

You should try to get a knowledge of germination as seen (*a*) in experimental cultures indoors; (*b*) in a garden plot, where you can vary the conditions; (*c*) in a farmer's crop.

Enter in your records particulars as to the proportion of seeds which germinate, and also the time required for reaching a certain stage in germination. You will find that if you have chosen good seed of the previous year's harvesting, the percentage of germinating grains is very high; ninety-eight per cent of first-grade seeds should germinate. Progress will be uniform amongst them. The older the seed, the longer the time required; it has been proved that Wheat grains forty years old will germinate; so far, that is the known limit. All seeds do not retain their vitality as long as this; on the other hand, some leguminous seeds have been known to germinate after being kept for about one hundred years. It is essential that such resting seeds should be kept dry. I once saw a striking example of the opposite of this condition in a Cheshire field during one exceptionally wet autumn. The Wheat stooks were soaked day after day with rain. The sheaves became miniature wheat-fields, for nearly every ear germinated where it hung, and the Wheat stalks carried many tufts of little leaves, each a young Wheat plant.

Laboratory Experiments. Place soaked grains on folded blotting-paper which must be kept wet; this, placed on a plate and covered with a glass shade, forms a convenient moist chamber. Include a sufficient number of seeds to make examinations of them at successive stages. If you choose, you may experiment with different temperatures; speaking generally, Wheat will not germinate at temperatures below 2° C. or above 50° C.

In grains plump with water watch what happens within the root-sheath. (Fig. 44). Two bulges arise at the highest part of the radicle; they are the rudiments of two secondary seed-roots. All three roots grow quickly and burst through the root-collar; the latter has been swelling up, and the combined pressure of all the parts ruptures the grain-coats. If the grain were in soil, the roots would get fixed at once and the root-hairs would get to work.

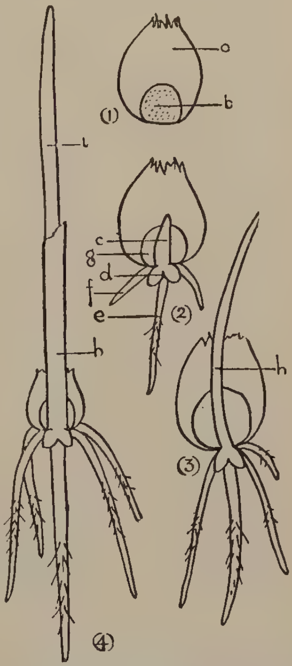

FIG. 44. WHEAT-SEEDLING

(1), (2), (3), (4) Stages in development.

a, grain; *b*, region of embryo; *c*, plumule; *d*, root-collar; *e*, radicle; *f*, adventitious root; *g*, scutellum; *h*, sheath of plumule; i, first leaf.

Next the plumule bud begins to stir, fed from the roots and from the endosperm. The development which follows is unusual. The three *seminal* (seed) roots make no further progress—indeed, their life is a short one. But new roots sprout from that part of the lengthening axis which may be taken as the base of the stem. These adventitious roots are the beginning of the root system of the adult plant.

The first leaf which leaves the plumule is rudimentary. It remains tubular, unbroken except for a slit near the top. Within it, upright and rolled, stand the younger leaves. The tip of the bract-like tubular leaf works a way upwards, unharmed, amongst the soil particles. The enclosed leaves are carried upwards by the lengthening of the internode between them and the origin of the tubular leaf. The first of them uses the slit for exit, and ultimately the sheath is ripped open at the top. Whilst the leaves are shooting up, the grain is shrinking and its contents are getting pulpy.

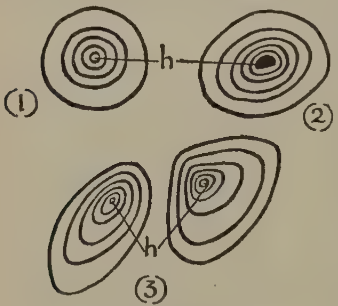

Fig. 45. Starch Grains: Diagrammatic

(1) Concentric grain from wheat; (2) Concentric grain from bean: hilum is hollow; (3) Ex-centric from potato. *h*, hilum.

There is not general agreement about the identity of the cotyledon. The scutellum has been mentioned as probably the most likely representative of it. In the opinion of some botanists it is the tubular leaf; others think that this leaf is an extension of the scutellum, and that the two together represent the cotyledon.

Water a pot of your seedling Wheat pretty freely one evening; look at it next morning. Every leaf is tipped with a dew-like drop which, however, is not dew. Absorption of water has been going on vigorously during the night and root pressure (p. 263) has driven the water upwards more rapidly than the leaves have been able to use it up or to give it off as water vapour, low night temperatures not being favourable to evaporation. It is pressed out of the vein-endings at the leaf-tip and collects on the surface.

[1] A microscopic and a chemical examination of Wheat grains should be made at intervals after sowing. Start with the grain directly after soaking. Make longitudinal microscope sections (Fig. 43), after locating the embryo and identifying its parts, examine the endosperm. The mass of it consists of large, thin-walled cells whose contents are obviously mainly starch grains; these are ovoid in shape and smaller than in the potato. A single-

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[1] This paragraph may be postponed till after Chapter XVI. has been read.

layered sheet of cells encloses the starchy endosperm and fits closely under the testa of the seed. Its cells are smaller, and their contents are much smaller, than starch grains. When the iodine test is applied to the whole surface of the section, the starch grains stain blue, but those grains in the external layer stain yellowish-brown. They are formed of a mixture of proteins called *aleurone.* As a further test, place some longitudinal sections of Wheat grains in an evaporating-dish. Pour hot nitric acid over them. Allow this to cool and add ammonia. The protein-containing areas of the section turn orange. The protein may be obtained in bulk from wheaten flour in a very simple way. Enclose some in a bag; let a stream of water pass gently over it, squeezing it the while. A liquid milky with starch drips off; within the bag is left a sticky lump of *gluten,* the protein, to which may be applied the nitric acid test.

The cells of the scutellum which are in contact with the endosperm become more prominent as germination proceeds. The starch alters; its grains waste, lose their regular outline, are split by cracks, and finally seem to dissolve. This they actually do. The transformation is the work of one of the enzymes (p. 109), *diastase,* which is believed to originate in the surface cells of the scutellum. Its duty as a ferment is to change the starch into sugar. The sugar passes, by way of the scutellum, into the growing parts of the embryo.

The whole store of starch is so used up; the protein also is changed and absorbed. The useless husk and derelict scutellum soon disappear.

THE WHEAT IN LEAF

Keep records, illustrated, of your seedlings. The illustration (Fig. 46) was made from a three-weeks-old plant grown in a city garden, taken up in May. Its root system is not as good as in a field plant, and no part is quite as far advanced. *a* is the origin of the first, tubular, leaf *b*. Strip *b* downwards; *a–c* is a cylindrical internode; *c* is a thickened node from which rise leaves. The second leaf is *d*; turn it back and look at the sprouting bud in its axil, and also at the small knobs which jut out at the sides. In some specimens these knobs have worked through the sheaths and are clearly young adventitious roots. At this stage the axillary bud may be leafy. These are important points. Node *c* lies within the soil; *e, e* are leaves which apparently leave the stem at *f, f*: they are on opposite sides of the axis, but not at the same level, and the origin is not really at *f*. Pull a leaf gently away from the axis; it is merely clasping it closely, and is slit right down to node *c* on the side opposite the free blade. In its axil at *c* is a bud. You have bared a smooth axis two to three inches long. Treat the next leaf in the same way; it too rises at *c* and possesses a bud. There may be only one leaf left now; its blade has opened flat at the top, but is still rolled at the bottom so that a couple of inches of cylindrical axis stands above node *c*. This axis is rolled leaf: unroll it until you reach a hidden leaf, finely pointed as a needle, perhaps about an inch long. The axis has vanished; it was a roll of leaf-bases, not a stem cylinder. It looks as if there were no stem above node *c*, and as if the leaves all rose from this node. Continued growth shows that this is not so. Each leaf has a node of its own; only the first one *d* belongs to *c*. The internodes between the leaves have not lengthened.

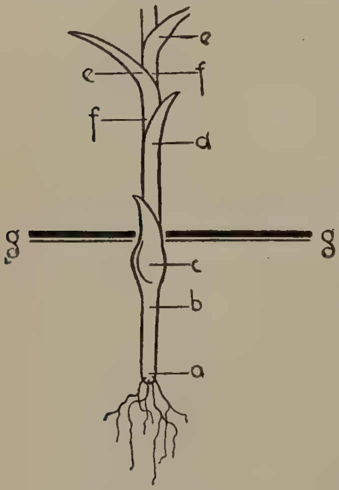

Fig. 46. City-grown Wheat: Three Weeks Old

Condition of plant in May 1927.

a, origin of first leaf; *b*, first leaf; *c*, thickened node; *d*, second leaf; *e*, *e*, succeeding leaves; *f*, *f*, places where *e*, *e* spread out from axis; *g*,— —*g*, ground level.

Examine a leaf. It consists of a very long narrow blade and a sheathing transparent base. This shape of leaf is that best suited to the crowded grass community; so is the upright position it takes up; light filters down and amongst the leaves so that all get a share of it. The leaf-blade breaks away from the leaf-roll at an abrupt angle. Examine this place; you find an upgrowth from the sheath, like a fringed scale, lying between the blade and the axis. It curves round the axis and ends in a few hairs at the top of the slit in the leaf-base. This scrap of green tissue is invariably present in Grasses; it is named a *ligule*. It is often said to prevent water from slipping down into the tube. More probably it is a relic of a structure which was much larger and of more service in an ancestral plant. The leaf-blade is finely furrowed; the veins run parallel, and the central vein is the best marked.

Throughout part of the month of May the products of the activity of the leaves and roots are expended on adding to the number of buds and adventitious roots at the ground node. The axillary buds send out their leaves as did the main stem, but for a time their internodes do not lengthen, and the aerial part of the plant is a clump of leaves. In the centre of the leaves every shoot can be recognised, the inflorescence fully ready to make a sudden burst of growth. This profuse branching from one or two nodes close to the soil, accompanied by the formation of numerous roots to supply their needs, is known as *tillering*. It is considered an important quality in a Wheat plant, for every branch will end in an inflorescence. It is more marked in certain varieties; it is encouraged by good light and good soil. The importance of light to the plant is shown when Wheat crops "lodge." This means that the lowest internodes are too long and weak to support the uppermost, which fall over. Excessive length of stem is the usual result of deficiency of light.

At the tillering stage special "white" roots arise. They are long and unbranched, and spread laterally; they are covered throughout their length—not just near the tip, as is usual—with root-hairs. The great increase in absorbing area which they provide at the time when new shoots require much nourishment is important. The possibility of encouraging the formation of "white roots" by means of manures is being tested in research stations. Barley and Wheat both respond.

At some time in June, almost at a given signal one might imagine, every internode shoots up, leaves and inflorescence thrown high. In Grasses, the growing region is not limited to the apex of the shoot. Growth goes on all over the internodes (*intercalary growth*), but is most vigorous in the belt just above the nodes. Its rapidity is so great that the tissues in the centre cannot keep pace, are torn to pieces, and a hollow stem is the result, which is common in quick-growing plants. The nodes remain solid right across.

Throughout June and July the plants are growing taller. Alternate green and white lines run down the stem, being continued into the leaves; stomata are confined to the green tracts. The gradual hardening of the stems is the result partly of the increase in fibrous tissue round the vascular bundles, but mainly to the deposition of siliceous matter in the cell walls of the epidermis. The stem is extraordinarily strong in its flexibility; the mechanical plan of a thin-walled cylinder with strong elements disposed around it is most effective. Such a stem is economical in material, is light, and recovers readily from bending. Another remarkable feat is possible. Wind or rain may beat the Wheat flat on the ground; it does not stay down. At the points where the soft tissues of the lower nodes touch the ground, cells which remain *meristematic* (capable of increase in size of division) are stimulated by the moisture in the soil. The underlying side of the stem lengthens more than the upper, a bend forms, and the stem above the bend becomes vertical again.

CHAPTER XI

THE LIFE-HISTORY OF WHEAT (*continued*)

THE WHEAT IN FLOWER

THE inflorescence is a spike which is compound but looks simple; it varies in different varieties. The " bearded " are distinguished by the wiry prolongations of the scale-tips, which may be as long as the spike itself. The grouping of the " ears " may be lax or dense. The scales may be red or white.

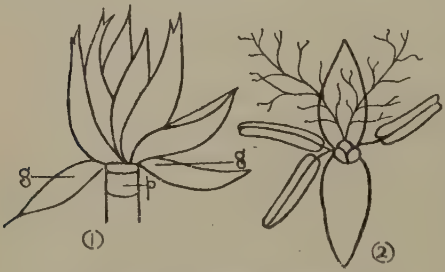

FIG. 47. WHEAT FLOWER
(1) Spikelet, partly opened; (2) Flower.
p, peduncle, cut off; *g*, glume.

Each secondary axis arising from the main axis of the spike bears three to five small flowers; we speak of it as a *spikelet* or " ear " (Fig. 47). Compare the inflorescence of Wheat with that of Barley with compound spike, and Oat which has a *panicle* or loose, repeatedly branched axis, each point in which terminates in a drooping spikelet or " ear."

A spikelet is a small group of flowers arranged on a plan which is unique. It is the tip of the outer flowering glume which may be prolonged as an *awn* or bristle. In Fig. 48 it is outlined.

Pollination. Obviously, the Wheat flower does not invite insect attention; there are no gay colours, no fragrance, no nectar. The botanist will have to rise early to see the opening of the mature flower. About 4 a.m., if the morning is warm enough, the flowering glumes spread apart and the stamens and stigmas are displayed. They flutter in the air for about an hour, and are then shut away again; a stamen or two may be left hanging outside. Wind may carry pollen hither and thither over the wheatfield during that morning hour, and the chances of cross-pollination are many. In addition, the stamens boxed up again may have some of their pollen clinging to them, and self-pollination is quite likely. Many cereals, including Wheat, are self-fertile, and in breeding experiments precautions are taken to prevent this. Grasses are decidedly *anemophilous* or wind-pollinated plants. The flowers of such plants are distinguished by the following characters: copious production of pollen, pollen grains with dry smooth surfaces, a large expanse of hairy stigmatic surface, wide-flung anthers. Other examples of anemophilous flowers are Poplar, Oak, Beech, Sedges, Plantains, Stinging Nettle.

Ripening of Grain. The fertilisation process is completed within a few hours of pollination. The stages of ripening are of interest; whilst they are in progress, the plant is dying off in other parts—the roots become inactive, the lower leaves fade, then the stems and upper leaves by degrees change from green to yellow. In history of the grain the grower speaks of:

(*a*) A milk-ripe stage, when the seed is soft, contains much starchy liquid, and when the glumes are still green.

(*b*) A yellow-ripe stage, in which the endosperm is doughy in quality, the stem and fruit-coat are pale yellow and dried up, and only the upper nodes remain greenish.

(*c*) A ripe stage, in which the seed is firm and all trace of green has disappeared from the plant—the safest stage at which to harvest the crop.

(*d*) A dead-ripe stage, when the grain is liable to break off the stalks, which with the stems are brittle.

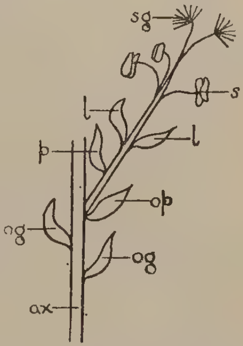

Fig. 48. Part of Spikelet of a Grass: spaced diagrammatically

ax, axis of spikelet; *og*, two outer glumes (scales) not quite at the same level; *op*, outer pale, subtending a flower; *p*, a pale, an inner flowering glume, smaller than *op*; the two may stand close together enfolding the other parts; *l*, lodicule, two very small scales which some interpret as a rudimentary perianth; *s*, three stamens, the filaments slim, the anthers versatile, swinging freely from the middle; *sg*, stigma.

Fruit formation is followed by the death of the plant, whose life is thus encompassed within one season. It is an annual. As is not rare, death may be delayed by hindering seed-production.

Classification

Wheat belongs to the Family of the *Gramineæ*, of which the characters are these:

Plants usually herbs.

Stem. Hollow internodes, swollen nodes, intercalary growth.

Leaves. Two ranks, blades linear or lanceolate, long sheathing bases split throughout length, ligule at junction of blade and base.

Inflorescence. Spikelets arranged in simple or compound racemes or spikes.

Flowers. Usually perfect.

Perianth. Absent or represented by scales.

Stamens. Usually three, filaments long, anthers versatile.

Pistil. One carpel, two feathery stigmas, superior, one-celled ovary with one ovule.

Fruit. A caryopsis, that is, an akene in which seed-coat and fruit-coat are indistinguishable.

Besides looking at Oats and Barley, it is well to examine some of the wild Grasses. There is much variety in the way in which buds develop into shoots, in the extent to which plants spread by horizontal stems, in the ligules, in the leaf-modifications, and in the inflorescences. Try to get some general idea of the adaptations of certain Grasses to particular habitats, such as meadows, woods, marshes, wet ditches, moors, seashore.

Couch Grass is one of our worst weeds, travelling by its quick-growing rhizomes. The tufted Mat Grass (*Nardus*) has only one stigma; Sweet Vernal Grass has no lodicules and only two stamens; the False Oat forms a pile of short bulb-shaped underground storage stems. Moorland Grasses, exposed to danger from drought, often have leaves rolled or folded in such a way that their stomata are not fully exposed. Marram Grass is noted as a "binding" plant of sand-dunes, by virtue of its long many-branched rhizomes. *Spartina* is the Cord Grass, which is an early colonist on salt-marshes.

Grasses are the herbage plants of the world; they are, too, the cereal plants; they include Rice, Millet, Maize, etc.; the Sugar-cane belongs to this Family. Numerically, the Family surpasses all others throughout the world, although the number of species (about four thousand) is not the greatest. Its range of form is great—from a turf Grass to a Bamboo eighty feet high.

WHEAT CULTIVATION: FAVOURABLE FACTORS

High-grade Wheat is a crop which demands good soil. Plant food must be abundant in the soil—especially nitrogen, lime and phosphates. The texture must be fine; strong grain with high nitrogen content can be obtained only on soils containing at least thirty per cent of clay or silt. The soil must be fairly retentive of water, but it must not be ill-drained; stiff clay soil is too cold and requires too much labour to be cultivated profitably. Sandy soils are unsuited, because they retain neither water nor mineral salts. The famous " black soils " of Russia and the United States are rendered eminently suitable by the large amount of humus they contain, which implies much nitrogen and high water content. River alluvium, old lake-beds, calcareous glacial clays mixed with sand are all of high value.

The annual rainfall of a Wheat area need not be heavy, especially if the soil is very retentive. It *is* of the highest importance that there should be no lack of moisture in spring and early summer, when " tillering " is in progress; the most favourable conditions for this include a cool, rather long, wet spring. The Wheat-growing regions of the world have in most cases an average yearly rainfall of less than thirty inches. Wheat is suited by a climate in which the winter is long and damp, the spring is wet, the summer and early autumn hot and dry. Too moist a climate encourages fungoid pests; a sunny climate is essential for bright, hard grain. Wheat is a plant of the temperate zones, succeeding in the tropics only at high altitudes.

Some Wheats are sown in autumn, some in spring. Spring Wheat is grown where the winters are cold and rather dry. Winter Wheat is usual in places where temperature and moisture permit of growth during late autumn and winter, an early start being thus secured and probably early ripening.

THE WORLD'S WHEAT CROP

An adequate supply of labour, up-to-date machinery for cultivating and handling grain, fairly level land, easy access to markets, and skilled farming, are essential to a great Wheat country.

Europe is of chief importance as a Wheat-growing continent. Partly because of the regularity of rainfall, but chiefly as the result of scientific farming, the highest yield per acre is found in Western Europe—in South-east England, Belgium, Northern France and Central Germany. It there reaches thirty-two bushels per acre, whereas the average for the world is only between thirteen and fourteen. Russia has an immense acreage, but a very low yield, in spite of its famous " black soil " areas; cultivation practices are poor. It is grown as far north as 62° N. latitude in Russia; most European countries are Wheat-growers.

In Asia Wheat is grown round Omsk and Tobolsk, in Asia Minor, in irrigated lands in Kashmir, Tibet and the Punjab, and on the alluvial plains of the North-Western Provinces. The rescue and restoration of the ancient Wheat lands of Mesopotamia is a modern enterprise.

North America is one of the world's granaries. Her great western plains have most lavishly generous soils, many being the fine silty loams which had gathered in the beds of glacial lakes. "There is no more exhilarating sight in the West than the prospect of the binders at work on the sea-wide, sky-skirted prairie, with the golden grain gleaming under the August sun, and above and about all the cloudless dome of heaven. And when the last sheaf has been cut and the binders are silent, how splendid is the view across the gently rolling stubble fields; stook beyond stook, stook beyond stook, for a quarter of a mile, for half a mile, and still more stooks as far as eye can see, stooks cresting the distant horizon, ten thousand stooks all waiting to be threshed and each with its promise of bread, the gift of the New World to the Old."[1]

The southern limit of Wheat in the United States roughly coincides with the 68° isotherm for the two months ending mid-June, its western limit is the western boundary of the States of Kansas and North Dakota; Wheat is the principal Canadian crop, and Central Canada has an ideal Wheat climate. The long cold winter is not a bar; culture goes on in April; rain comes in May, and most of it falls before the end of July. The summer days are long and bright; autumn is dry; harvesting is done in August, and ploughing can begin in September. In one of the phenomenal years, 1915, the Prairie Provinces produced 360,000,000 bushels of Wheat.

Attention is now being turned to the less favourable land. More than half of Central North America is arid or semi-arid, and this has been reclaimed on the scale of many millions of acres. Huge irrigation schemes have dammed up valleys as reservoirs, cut canals, diverted rivers, even tunnelled a water-channel through a water-shed from valley to valley. All the Wheat land of Arizona, for example, is dependent on irrigation.

In South America Wheat-growing is almost confined to part of the Argentine and Uruguay, those parts served by railways. In Chile, Wheat is possible at elevations of 12,000 feet on the Andes.

The Mediterranean littoral is famous for its Wheat. Egypt grows Wheat wherever the Nile floods and the irrigation works make it possible.

Abyssinia (8000 to 11,000 feet), Northern Rhodesia, Basutoland, and parts of Cape Colony and the Transvaal produce Wheat.

In Australia most of the continent is too hot and dry, whilst the east coast is too moist, for Wheat. Good crops are grown in Victoria, New South Wales and South Australia. New Zealand produces Wheat on the Canterbury Plains, and in Otago in South Island.

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[1] A. H. R. Buller, *Essays on Wheat.*

British Wheat

Over a large part of the British Isles so little dependence can be placed on hot, strong sunshine for ripening, that Wheat cultivation is limited severely. The chief districts are in the middle and south-east. The elevation is limited to 800 feet. In Scotland it is a crop only on the best and most sheltered farms of the Lowlands.

The botanical research stations are giving increasing assistance to British growers of cereals. Cambridge has its Plant Breeding Institute, concentrating on cereals; Aberystwyth specialises in grasses and forage crops; Edinburgh and Belfast are plant-breeding and seed-testing stations. The work in the laboratories is linked up with field trials. Some grains already proved to be sound are: better baking qualities in Wheat as in the *Yeoman,* suited to English bread-making; Wheats immune from rusts and mildew; Wheats and Oats specially useful for thin soils at high altitudes under heavy rainfall, as in Wales; Wheats not liable to "lodge"; new Barleys of high yield and good malting quality. Of much interest is the discovery that the variation in "strength" of Wheat is connected with the way in which the proteins of the seed are built up during the period of its ripening. Co-operation between the experimental botanist, the crop-growers and the crop-users is being strengthened.

The Cornfield: an Ecological Study

Two ruling factors must be recognised in the Cornfield community:

(1) The crop plant has a root system which very quickly takes almost complete possession of the soil, and which makes exhaustive demands on it.

(2) The crop plant is a very quick-growing annual, which attains considerable height, and the individuals are crowded together. It is clear that any other plant will have poor chances of food and of light. Let us see what does live amongst the Corn throng and how it does it.

You may learn something by inspection of the margin of the field at all seasons; this cannot, of course, be taken as an index to the field, but it shows something of the weeds of cultivated land. A field should be kept under observation directly it has been sown, every yard of ground harbours seeds lying dormant; watch how many of them thrive in this well-prepared soil. Watch what follows: some carry on, but most of them are smothered out by the quick-growing thousands of Corn seedlings. After the crop is harvested, go over the stubble-field and make a list of the plants now seeing broad daylight after weeks of twilight. Some few little things have never risen much above the ground. Examine the sheaves, and pick out the remains of longer-stemmed plants mixed with the straw. If you have a chance of comparing Oat-, Barley- and Wheat-fields, you may detect general differences in at least the amount of associated vegetation. Notice what kind of growth develops in the stubble-field after the crop is removed; some plants lose no time in starting forward. Often there is a good deal of Clover. An investigation of this kind calls for the co-operation of a whole class; sometimes country members of a class can help their class-mates greatly by bringing specimens and sets of observations.

The effects of light deficiency are very evident. Those plants which live along with the full-grown or nearly full-grown crop have very attenuated, straggling stems and small linear leaves. Their flowers are meagre, and they are self-pollinated, for rarely do they overtop the Corn. Amongst them may be Knotgrass (*Polygonum aviculare*) and Corn Spurrey (*Spergularia arvensis*). The flaunting Poppy is probably the first Cornfield weed you think of; it is an annual. It grows very quickly and keeps its leaves well abreast of the Corn-leaves, until it has sent its flowers still higher and done its seed-making. The Cornflower (*Centaurea cyanus*) and the Corncockle (*Githago segetum*) have slender stems and narrow variable leaves.

On the edges of the field, amongst others, these are of common occurrence: Fumitory, Spurge and the Meadow Convolvulus.

Nearly all the Cornfield weeds are annuals. There are three, however, which are perennials, and which no ploughing can destroy. They are the Couch Grass and Coltsfoot, with long rhizomic stems, and False Oat, with a tuberous stem. They may be cut to bits by the plough, but each bit, if it includes a node, is a potential new plant; their stems contain food enough to support them for months. Even if they make little headway above the ground whilst the crop is standing, they are ready for an aerial campaign as soon as it is gone.

A Pasture-Field: an Ecological Study

Make a fairly detailed study of the vegetation in a pasture-field, taking one in which there is diversity of level and of soil conditions if you have any choice. This will serve as an introduction to grassland in its broader aspects.

Make a plan of your field drawn to scale, and, if it needs it, insert contour lines. Represent plant species on the plan by means of symbols. (There is not space here to indicate detailed methods.) The notes appended to the plan should include every kind of information which has a bearing on the vegetation. The aspect may be important if the slope is steep; rainfall may be a useful record; the underlying rock should be known, and the rock of higher slopes from which soil may be washed down. A stream, pond or ditch should be noted; also rabbit burrows or mole hillocks and their influence. Information must be got as to the history of the field—whether ploughed and how often, what animals are put to graze on it in the course of a year.

The pasture-field is a *closed* plant association; it would be difficult for additional species to get entry into it. It varies greatly according as it is (*a*) permanent pasture, i.e. land which is never ploughed, but grazed year after year; or (*b*) meadow, which periodically is ploughed and manured, may be sown with meadow Grasses, and may be mown once or more than once in a year. The quick-growing Grasses which are sown are strong enough to kill off most of the weeds.

The dominant of the community is Grass; the particular species of Grass depends on drainage and the mineral content of the soil. Some of the Grasses which appear in permanent pastures are Sheep's Fescue, Mat Grass, Sweet Vernal Grass, etc. In the hay-meadow are Sweet Vernal, Rye Grass, Timothy Grass, etc., together with Clovers.

The plants of the permanent pasture-field are almost uniformly of low compact habit. This is due largely to the severe biting down by grazing animals; this acts like the repeated mowing of a lawn, the herbage being reduced to a close-set turf—with this difference, that what the animals do not like is left standing. Amongst these exceptions are the Spiny Thistle and the Acrid Buttercup. The inflorescences go the same way as the leaves, which is very serious, as it cripples the plant's means of multiplying; the individual plant may keep alive, but can do no more. The field Grasses are tufted in habit. Many plants (e.g. Daisies and Sheep's Sorrel) form rosettes; their leaves spreading around them close to the ground keep a space clear for the plant; their buds are either quite close to the soil or slightly sunk in it; only thus can they escape the eaters. Creeping plants like Dutch Clover, Wild Thyme, Bird's Foot Trefoil, have a chance of spreading. Some of the plants have leaves which would be able to compete for light with Grass leaves if they were permitted to grow; the leaves may be linear (e.g. leaves on erect stems of Harebell), or much dissected (e.g. Pignut). In both cases light enters freely amongst them.

Animals are almost in full control of a field community. If a wood borders a field which is not grazed, there are chances for the woodland seeds to germinate in the field. If they escaped the attentions of rabbits, etc., they might ultimately carry the woodland association forward into the grassland. But grazing animals destroy such seedlings absolutely. If a small plot within a field can be effectively fenced off from all sheep, rabbits, mice, the rapidity with which luxuriant growth develops within the enclosure is an astonishing contrast to the close-cropped turf outside. Animals influence the field conditions in another way, by adding manure.

They also act as carriers of fruits and seeds, both on their feet and on their coats. They may be of some service to the plants by trampling seeds into the soil.

The field vegetation is not uniform as regards species. Celandine colonies may be confined to hollows slightly damper than the rest of the ground; a sheltered corner favoured by sheep as a resting-place, and therefore heavily manured, has a rank collection of Nettles, Dock, etc.

A few of the weeds of the pasture may be: Buttercups, Daisy, Field Rush, Thistles, Lady's Mantle, Dandelion, Sheep's Sorrel, White Clover, Earthnut, Hawkweeds, Eyebright, etc. A complete and universal list is impossible; make one for your own field.

The Grass association in the meadow grows much more freely. A few of the plants associated with the Grasses there may be: Buttercups, Ragwort, Self-heal, Yellow Meadow Vetchling, Meadow Cranesbill, Ribwort Plantain. Add more to this list.

Successful competitors of the Grasses must either have roots long enough to get their food from strata below the Grass roots, or they must steal from the Grass roots. Many of them do steal: they belong to the class of semi-parasites (p. 139). They include Yellow Rattle, Eyebright, Bastard Toadflax, etc.

CHAPTER XII

THE FOOD OF PLANTS

It is not very difficult to find out what elements are essential to the plant as food; nor, now that chemist and physicist know more about earth, air and water, is it too difficult a task to learn how it gets them. There is a true scientific story about a botanist who, working in the early years of the seventeenth century, drew from his experimental work the conclusion that a plant obtained *all* its substance from water. His famous plant was kept for five years in a jar of soil, and put on weight enough to bring its original 5 lb. up to 169 lb. The soil had lost only 2 oz. out of its 200 lb. Nothing but pure water had been added to the soil during the five years. Hence the increase of 164 lb. minus 2 oz. must have come from the water: so they reasoned. The clear emptiness of air was never suspected as a source of solid plant tissue. Chemistry has gone far since then, and sees nothing magical in extracting coal from air. We have already seen (p. 106) how some plant food comes from the air; we pass on now to inquire about the rest of it.

Chemical Elements always found in Plants

(*a*) By heating it at 100°, drive off from a quantity of plant material the free water which it contains. This can be done by keeping it for a considerable time in an evaporating-dish over a water-bath. It is weighed at intervals until no change in weight is shown. By calculation the loss of water is ascertained, and the ratio of *dry weight* (the remainder of the material) to *fresh weight* (the original material) is worked out. Nearly two-thirds of the weight of herbaceous plants may be water, and about half the weight of woody plants may be water.

(*b*) The next proceeding is to *burn*, i.e. destroy at a very high temperature, the dry residue from (*a*). This breaks up such of it as is combustible into constituents which are volatile, and therefore disappear as vapours. These can be collected and identified. They include nitrogen, carbon dioxide and water.

(*c*) The ash which is left in the crucible after (*b*) is analysed. It represents the mineral constituents of the plant.

The results obtained by such experiments are:

From (*a*) the hydrogen and oxygen of water;
(*b*) carbon and nitrogen;
(*c*) sodium, potassium, magnesium, sulphur, phosphorus, calcium, chlorine, iron, silicon.

Although these are always present, they do not seem to be all essential; sodium, chlorine and silicon can usually be done without; the other ten must be present. In all, over thirty elements have at one time or other been found in plants, including manganese and iodine.

Culture Experiments should be made to distinguish essential from non-essential food materials. They may be (*a*) water-culture, or (*b*) sand-culture experiments.

(*a*) *Water Cultures*. The principle on which these are carried out is that of growing plants in water solutions of known chemical composition. One solution contains all the elements generally found in plants by the methods outlined above; then from each of the comparative culture solutions there is omitted in turn, a single element.

Details of fitting up this most important experiment are left to those who set it up; only general directions are included here.

Prepare a number of wide-mouthed glass jars which will hold about a quart and a half. Disinfect them by rinsing with strong nitric acid, followed by thorough washing out. Their cork stoppers must be slit and bored so as to take a thin plant stem in the middle, and also a glass delivery-tube; they also must be sterilised. Select a set of small herbaceous shoots, or of seedlings, as nearly equal in size and vigour as possible. A successful school experiment was carried out with slips of *Tradescantia*; another suitable plant would be *Fuchsia*. Seedlings of Buckwheat, Pea, Maize, Wallflower are recommended; germination should be carried out on moist blotting-paper or in clean sand; all endosperm or cotyledonary food should be removed.

The *normal* is a standard solution which is supposed to contain all the mineral elements necessary; it may be varied, the experimenter remembering that the solutions must contain all the elements in the plant ash, and that plants have preferences in the compounds from which they select any particular element.

A solution (normal).

Distilled water . . .	1000 c.c.
Potassium nitrate . . .	1·0 gm.
Magnesium sulphate . . .	0·25 gm.
Ferrous phosphate . . .	0·5 gm.
Calcium sulphate . . .	0·25 gm.
Sodium chloride . . .	0·5 gm.

B solution. *Cut out nitrogen* by substituting potassium chloride for potassium nitrate.

C solution. *Cut out potassium* by substituting calcium nitrate for potassium nitrate.

D solution. *Cut out magnesium* by leaving out magnesium sulphate: there is sulphur left in the calcium sulphate.

E solution. *Cut out sulphur* by using calcium nitrate and magnesium chloride instead of calcium sulphate and magnesium sulphate.

F solution. *Cut out phosphorus* by substituting ferric chloride (a trace) for ferrous phosphate.

G solution. *Cut out calcium* by leaving out calcium sulphate: sulphur remains in the magnesium sulphate.

H solution. *Cut out iron* by substituting calcium phosphate for ferrous phosphate.

I solution. *Sodium* and *chlorine* can be cut out together by leaving out sodium chloride.

J solution. *Cut out everything.* Use as control a jar of distilled water.

Label the jars securely as soon as filled. Set up the culture jars side by side, giving the plants equality of light and warmth. Arrange that the jars should be in darkness; this makes things more normal for roots and checks the growth of some lower organisms in the solutions. It can be done by enclosing all of them in a light-proof box, or by covering each jar with a black cloth bag or a cardboard case.

Fix the specimens upright into the corks, plugging round with cotton-wool; the solution should not quite fill the jars. Be careful not to have any damp about corks or cotton-wool. Aerate the solutions occasionally by blowing air in through the glass tube (which should reach nearly to the bottom of the bottle) whilst raising the cork a little. Change the solutions about once a fortnight. Keep tabulated records of the growth of the plants. Do not forget to watch root-growth.

Results resembling the following will probably appear:

A solution gives good strong growth as in soil. If kept going long enough it may carry the plant on to the flowering and fruiting stages.

B solution. If no nitrogen at all is given there is a cessation of growth after a very short time. If the quantity in the normal solution is reduced to half, leaf-growth is very poor and the leaves are yellowish. When a cultivator wants excess of leaf-growth, e.g. in cabbages, he applies nitrogenous manures.

C solution. Potassium starvation means poor growth and leaves mottled with brown.

D solution. There is fair growth at first, then a check.

E solution. There is poor growth from the first and an early stoppage.

F solution. Lack of phosphorus shows particularly in the meagre development of roots. Plants are small.

G solution. With calcium absent the plant makes very little progress.

H solution. The absence of iron is soon apparent. The leaves turn pale yellow. That is soon followed by stoppage of growth. Mark the time when the seedling has used up the infinitesimal amount of iron in the seed and the new leaf is yellow instead of green. An extremely small amount of iron will suffice; the yellow leaves of the iron-starved plant will turn green if they are painted over with a solution of iron salt.

I solution. The plant grows quite as well as in **A.** These two elements are not essential.

J solution. If the water is perfectly pure the plant soon dies.

Additional tests may be made in which substances are reduced in quantity but not entirely left out.

Through recent experiments it has been found out that, in the case of certain plants, the element *boron* is necessary as a stimulant, though not as a food. The discovery is important because the plants which demand boron include Broad Bean, Lucerne, Scarlet Runner and some Clovers. Extremely little of the substance suffices, and the necessity for it has probably not been noticed earlier because most of our soils contain it. "The investigation has taken four years to complete, and involved delicate working methods. The quantities of the element to be added to the culture solutions are so minute that the nutritive salts have to be submitted to a spectroscopic examination to make sure that no boron is present unless intentionally added."[1] This gives a hint of the difficulties of research work.

(*b*) *Sand Cultures*. Thoroughly cleansed quartz sand will furnish no plant food with the probable exception of a little iron. Leaving out the iron test, it can be used with the same solutions as in the water cultures. The sand must be drenched with weak sulphuric acid which must be washed out by prolonged rinsing under a tap. The plants are grown in the sand, in flower-pots. The watering with the various solutions must be done regularly and in carefully calculated and equal quantities.

Sometimes the use of a substance within the plant can be determined. For instance, the substance of the protoplasm must be renewed, and that involves proteins which contain certainly the elements carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus. Potassium may not be part of protoplasm, but it affects its building up in some way; the same may be said of calcium. Chlorophyll contains magnesium; no iron is actually found in chlorophyll, but it is certain that without iron chlorophyll will not be formed.

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[1] *Research and the Land*, p. 99.

Feeding Soil with Manures

A plant which continues to thrive in a wild spot has evidently found soil which contains all it needs. It may be otherwise in cultivated ground from which crops are taken. In order to replace what is taken from the soil as crop, as well as to stimulate plants for heavier cropping, the cultivator enriches the soil with feeding-stuffs—manures. Skilled cultivation is based on the scientific knowledge gained largely through culture experiments.

(*a*) *Nitrogenous Manures*. These stimulate general growth, and particularly leaves; rank herbage will result from overdoses of them. Sodium nitrate (Chile saltpetre) and sulphate of ammonia are common applications; soot furnishes ammonia.

(*b*) *Phosphate Manures*. These favour root-production in the early stages, and hasten ripening in the later stages. Basic slag, which also contains lime, is alkaline, and therefore useful to counteract acidity in soils near towns. It acts slowly and should be put into the ground in autumn. Superphosphate has an acid reaction and suits normal soils; it acts quickly, and should be applied in spring. Guano gives nitrogen, phosphates and potash. Bone meal is rich in the calcium phosphate of bones which have been burnt and crushed; it is favoured for roses.

(*c*) *Potash Manures*. They help in the storage of starch and sugar; they are employed for potatoes, beet, etc. Kainit is one of the most important. Potash remains in the ash when woody vegetable matter is burnt; the ash should be collected and used for young spring plants; potash salts are so soluble that they soon wash out of the soil.

(*d*) *Calcium Manures*. These are discussed under the head of lime on page 157.

(*e*) *Farmyard Manure* and the decaying matter in heaps of leaf-mould contain plant food of various kinds.

Very important research has been directed during the last ten years to finding out if the growth of crops can be improved by the application to them of electrical discharges. Pot-plants have been tested under conditions of perfect control, as well as field crops of cereals, clover and hay. There is evidence that electrical stimulation may be highly beneficial; of particular promise are the results with spring-sown Oats, Barley and Clover. Much work remains to be done before an application to practical farming can be suggested.

Abnormal Modes of Feeding

The green plant it is which keeps the world alive; no green of grass and tree—no life of animal or plant. The law is absolute. From simple inorganic substances of the soil and from the gases of the air, the plant can build up complex organic substances—sugar, starch, protein. But to do this it must employ the energy of sunlight, and in some unknown way the green colour chlorophyll acts as the agent which sets this sun-energy to its work within the leaf.

But there are plants which possess no chlorophyll. Clearly they can live only by following the example of the animals and feeding on what the green plants have laboured to make. The whole class of Fungi have taken this road to ease. They are spoken of elsewhere (p. 295). In this chapter we will confine ourselves to Flowering Plants which, either wholly or partially, have given up manufacturing their food from inorganic matter. Chlorophyll has vanished entirely from some, is much reduced in quantity in others. Some prefer live victims, some are content with the dead.

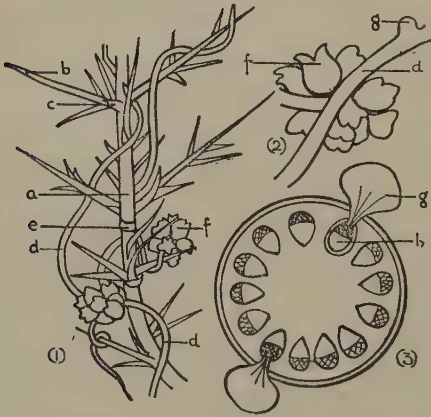


Fig. 49. Dodder Parasitic on Gorse

(1) Parasite in flower; (2) Cluster of flowers, enlarged; (3) Suckers (oblique section) penetrating vascular bundles.

a, main stem of Gorse host; *b*, branch spine; *c*, leaf spine; *d*, stem of Dodder, long internodes; *e*, tight coil of *d*; *f*, flowers of Dodder; *g*, sucker; *h*, vascular bundle of Gorse stem.

A. Those plants which subsist by robbing a living *host* are known as *parasites*. There are degrees of degradation amongst them, all of which can be illustrated amongst British plants.

The **Dodders** (*Cuscuta* spp.) are the most degenerate. They frequent the hedges, the heaths and the Clover-fields; amongst their best-favoured hosts are Gorse, Heather, Nettles, Flax, Hop. Only when it is in bloom does one think of Dodder as a live plant, and then the mingling of its pale purple flowers with those of such a plant as Gorse is bewildering (Fig. 49). Begin a study of it at this period. The inflorescences resemble clusters of little Convolvuli, to which Family Dodder belongs. It is hard to believe that they really spring from the withered thread-like stems which are tangled in every direction amongst the Gorse branches. Mere scales represent leaves. There is not a suspicion of green about the whole plant. The fruits are capsules and the many minute seeds are wind-scattered. A great quantity of seed is necessary, because to the usual risks of germination is added the precarious business of finding a green individual who can be made to act as a provider. The parent dies at the end of the season; the seeds lie in the ground all winter. Quite late in the following season, after other plants are well started, the Dodder seed wakes up. The seed has been reduced to mere rudiments. The embryo is a slightly coiled filament; one end sticks itself into the soil, the other pushes up into the air. It lifts itself thread-like, and its tip circles round like an upreared worm in search of something. It *is* searching, and when it finds a living support it winds round it. It has preferences, and if a support is not to its liking it untwists. Then the performance may be repeated. Success must come soon or it falls prostrate, able to rise again if touched by a suitable supporter—otherwise it dies, for it has no power to form the most meagre root or functional leaf. If it finds the host it wants, its twining stem clings closer, and the thread connecting it with the soil breaks. The thing which could not compass a simple root, begins at once to thrust forth, at spots where it touches the host stem, rows of pointed projections which steadily pierce a way deep enough to touch the internal tissues which are conveying water, etc., through the plant. In the sucker, or *haustorium*, a conducting tissue forms; it unites with the tissues in the host and the connection is complete. Dodder can now live in idle comfort; nourishment flows to it in plenty, ready-made.

Dodder branches freely and the branches repeat the doings of the parent. In strong contrast to the miserable vegetative organs is the unimpaired character of the reproductive organs; so it is with all parasites. One can fancy that Dodder was once a normal twining plant, that by chance it lit upon an easy way of getting food without work, that by degrees it ceased work, and that, as a consequence, the structures specialised for work (leaves and roots) were aborted.

Mistletoe is less depraved than Dodder. It never has a connection with the ground, but it does utilise the air. Its favourite hosts are Black Poplar, Apple and Silver Fir. Once it is established on one of these it may live for scores of years and send out colonies of dozens of its kind. Its fruits are sticky berries, much in demand by birds. They are the agents of dispersal, either by rubbing off the seeds from their beaks, or by passing them through their bodies and leaving them on branches as their excrement. It is in a cranny of bark that a seed germinates. It sends a special kind of root through the bark into the tissues of the branch. In course of time it links up with the water-carrying tissues there and taps their supplies. Year after year this parasitic root system extends, inwards, and up and down within the branch, following the layers of the wood. Externally, a bush of short branches is formed; it bears fair-sized leaves of yellowish green. From its host Mistletoe takes water and mineral salts, and possibly more; from the air it gets carbon and oxygen; having chlorophyll, it can manufacture its own starch, sugar, protein. It is a *partial parasite.*

Toothwort (*Lathræa squamaria*) attaches itself to roots of trees and shrubs; commonly it attacks Elm and Hazel, but it is not too exclusive (Fig. 50). We may expect to find it in woods and under hedges. Dodder and Mistletoe may possibly have adopted their peculiar style of life in the course of struggles to get sufficient light. The ground vegetation of the woodland, however, suffers not only from feeble illumination, but often from unfavourable soil. Where the fallen leaves do not decay quickly enough (p. 154), a kind of humus which is harmful to plants, gathers on the surface, and the shallower-rooted plants do not get easily the soil solutions they require. The result is that the wood population includes many plants which use organic food made by the deeper-rooted plants. Toothwort is one of these. It is a *complete parasite.* All that is visible above the ground is an inflorescence; there is no trace of chlorophyll. The inflorescence is stout, bears membranous scales and many small flowers—all tinged with purple. The seeds start life in an ordinary sort of way. Root and rootlets first get active, but they direct their efforts to finding small roots of a woody plant. As soon as the sucker touches a root it swells up at the point of contact into a

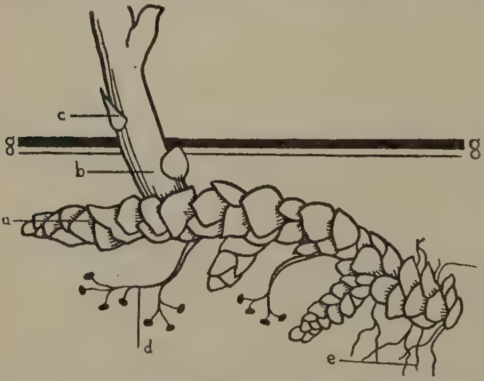


Fig. 50. Toothwort: Underground Structures

a, thick scale leaves; *b*, stalk of inflorescence; *c*, bract on inflorescence; *d*, parasitic roots with haustoria; *e*, saprophytic roots; *g*——*g*, ground level.

small disk, which sticks there. From the centre of the disk a sheaf of absorbing cells grows outwards and strikes down to the wood of the root attacked. There they take what they want in the usual way. It is possible now for the other end of the young plant to push ahead. A branching shoot and leaves develop, but they never leave the subterranean darkness. They remain white, and are uniformly thick and fleshy. Many new roots arise and form thready nets on every root available. The leaves nearly hide the rhizomic stem, and, as leaves, are unique. Thick, squat, white, they are rolled so as to enclose a very small cavity. Leaves exposed on open moorland do this in order that they may have a chamber into which their stomata may open without too great a loss of water. Toothwort does it because it finds difficulty in getting rid of water by surfaces touching soil all round. The leaves are "tooth-like," hence the name; they are set so closely as to hide the stem. The tips of some branches turn upwards and emerge as the inflorescences.

Broomrapes resemble Toothwort in their general characters. They are partial to Ivy and Clover. Chlorophyll is absent. The inflorescence is the only aerial part; it is erect, thick-stemmed, and brownish in hue, as are its scaly leaves. It produces abundance of seed.

In pasture-fields and similar places where root competition is very severe, a group of plants belonging to the Snapdragon Family has kept a place by becoming semi-parasites. They include Eyebright, Yellow Rattle, Cow-wheat, Bartsia and Lousewort. Their foliage often inclines to be yellowish green and is often rather scanty. In every case these parasites fix their rootlets on the roots of Grasses, etc., by means of disk-like suckers. An outgrowth from the centre of the disk penetrates to the wood of the host root and feeds there. Dig up sods containing some of these plants, pull them apart gently under a tap of running water, and trace the union of the two individuals. These grassland parasites are a very successful tribe, as you will realise on looking at a meadow thronged with Yellow Rattle or a copse peopled with hundreds of Cow-wheat.

B. The group which lives on the remains of plants and animals seems less guilty; they are the *saprophytes*. Only three British Flowering Plants are absolute saprophytes. They are the **Yellow Bird's-nest** (*Hypopitys Monotropa*), the **Bird's-nest Orchid** (*Neottia Nidus-avis*) and the **Coral-root** (*Corallorhiza innata*). They should be searched for amongst the humus of woods; the Orchid is most frequently met with in thick Beech woods. Only when flowering do they show above the ground; little or no chlorophyll is present. The one you are most likely to find is the Orchid, which blooms about the end of May. Its matted underground branches suggest a "nest." The Coral-root has no root; it is its branched rhizome which is provided with root-hairs. The Bird's Nest has numerous roots. In all three cases, the plant takes its carbon and nitrogen from the decaying organic matter in which it is embedded; not by its roots, and not by anything like the suckers of Toothwort, etc. Such plants introduce us to a curious association between two plants, the fungus member of which acts as a conducting medium; they are again referred to under section *C.*

C. In a sense this is not a new class of plants. We may call the plants included in it mutual parasites, with an admixture of saprophyte.

Who would dream that a Scots Pine or a great Beech-tree was not perfectly independent? Yet they do depend on a very lowly plant for vital things. If you examine the very finest rootlets of a Beech-tree you will notice the absence of root-hairs, but the presence in the root-hair region of a web of delicate filaments; examine them under the microscope. These filaments are the simple vegetative organs of Fungi (see p. 296 for full description); they are not unlike *very* long root-hairs. They have no chlorophyll, which is characteristic of Fungi. They are also fungoid in that they can and must utilise organic matter as food. The extent of their influence on the feeding arrangements of many green plants has come to light in recent research.

Apparently there are two forms which the association between the two plants may take. In one, the Fungus remains outside the root but close against it. In the other, it actually penetrates. The roots of forest trees often (the shallowest of them, at least) spread in soil to which rotting vegetation is constantly being added. It tends to be poor in the nitrogen of nitrates which the tree roots normally make use of, but rich in nitrogen locked up in unaltered humus or partially altered humus. It is only in such acid soils that Fungi form extensive mycorhizal connections with Pines. It is pretty certain that the Fungus absorbs (as a root-hair might) water with its dissolved salts, and transfers them to the tree. The Fungus is capable of passing on such inorganic compounds of nitrogen as potassium nitrate; it is, however, of more significance that it can take into itself, and give to the tree, *organic* compounds of nitrogen, which the tree is incapable of taking from the decaying humus. These may be the simpler amino-acids or the more complex proteins.

In the case of the three saprophytes mentioned in *B* the partnership is much more intimate than in the trees. Their much-branched subterranean parts are certainly enmeshed in hyphæ (filaments), but the hyphæ go farther. They apply their tips to the epidermal cells of the bigger plants, dissolve these by the enzymes they form, and after entry, pass between the tissue cells and even into them. Their trail is a curious one. In some of the cells (in microscope sections) they can be seen enjoying healthy life, in safety, and no doubt feeding well. In others lie piles of their remains; the plant is feeding on them. The organic substances which Bird's-nest Orchid and the others cannot make for themselves because of their lack of chlorophyll, the Fungus (which also shows that lack, but which has the power to take into itself organic substances already made) takes supplies of from the humus of the forest floor and shares with the higher plant. It is considered that the three flowering saprophytes, in addition to what they get from the Fungi, are able to help themselves directly from the humus.

It has been proved that some of the plants which live in the peaty soils of moors, where mineral salts in general and nitrates in particular are scanty, have a fungal associate from whom they must not be parted. This is particularly true of Heaths. The very youngest Heath seedling must have its hyphal companions if it is to live. They are born with it, as it were, for their rudiments lie ready in the seed-coat which covers the embryo. There are many other interesting examples which we must leave for the present.

The comprehensive term which is used to denote such a living together in mutual helpfulness is *symbiosis* (cf. p. 300). This particular partnership of fungus and root is a *mycorhiza.*

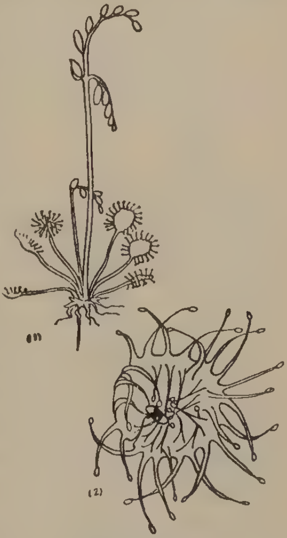


FIG. 51. SUNDEW

(1) Plant in flower; (2) Leaf further enlarged; some of the tentacles have closed in over an insect.

D. There are saprophytes which kill and then eat, and their prey is animal. They are often very charming in appearance.

Three of them are to be found in Britain—the Sundew, the Butterwort and the Bladderwort. The first two inhabit marshy spots, and the third stagnant water. All three possess normal amounts of chlorophyll, and can build up carbon compounds. Their difficulty is to get sufficient nitrogen from their special soils, which are distinctly deficient in it. Sundew and Butterwort have very poor root systems, and Bladderwort has none at all. They have, however, discovered a way of supplementing their legitimate supplies of nitrogen.

Sundew, of which there are three species in Britain, is fairly common in some localities. Amongst the fresh soft herbage of the bog Mosses its rosy rosettes of leaves are very attractive; they are meant to be (Fig. 51). Each spoon-shaped leaf on its stalk holds itself out invitingly. It is fringed and dotted with tentacle-like hairs; on every one of their knobbed heads glitters a drop of clear gum, distinct against the red of the leaf. A spoonful of honey? A trap, baited for flies—a trap which works very well. Thinking of his honey-feast, the fly alights and, of course, sticks in the gum. A chain of events follows. Sensitive to contact, the tentacle which was touched not only bends towards the centre carrying the fly, but in some way sends an exciting impulse to the other tentacles. Very quickly they curl over, the fly helpless in their clutches. Then certain glandular cells on the leaf-surface pour out a fluid which, in its action, is identical with one which, in an animal's digestive canal, acts on proteins. This fluid acts on the proteins of the fly's body and changes them into amino-acids. In this form they can be absorbed by the plant, and certain other cells on the leaf-surface specialise in this work. It is purely animal feeding. After everything useful is consumed the tentacles open out, secrete more gum, and resume trapping operations. It is possible to experiment with Sundews to see what they will try to eat. They can discriminate; to particles of dust or bits of hair they remain unresponsive; scraps of meat or egg they close down over and at least try to digest. Charles Darwin made a special study of these and others of the *Insectivorous Plants*, as they are called. His book on the subject is interesting reading.

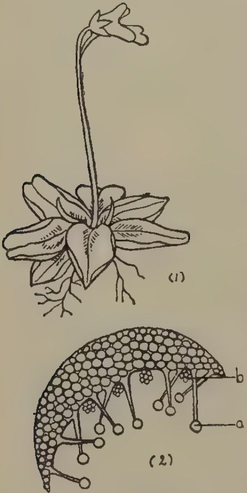


Fig. 52. Butterwort
(1) Plant in flower; (2) Section of leaf, showing glands.
a, stalked gland; *b*, sessile gland.

Butterwort's pale yellowish-green rosettes of leaves are easy to identify (Fig. 52). When you pull up a plant, its leaves, which had been forcibly pressed against the soil, suddenly drop downwards. The whole upper surface of the leaf is sticky with a secretion which collects within the trough of the uprolled leaf-edges. Generally it is strewn with little insects in all stages of decomposition and digestion—for digestive enzymes are in operation here as in the Sundew. Again the products of digestion are taken into the plant body.

Two sets of specialised hairs can be detected on the upper surfaces of the leaves. Three functions might possibly be assigned to them, namely, the excretion of the sticky fluid, the formation of the enzyme, and the absorption of the products of the enzyme action. Definite information on the allocation in each case does not exist.

Bladderwort inhabits the dull ditch-water, the peaty mountain pool, and the lowland pond. Rootless, having stems that are string-like and leaves that are thread-like, it floats under the water, the only part that reaches the air being the flower (Fig. 53). This plant bears many unique, bladder-like structures. The entrance to one of these is small and fringed with bristles. Water fleas and other small creatures get lost among the bristles, and may be tempted through the doorway. The door opens easily enough to admit them, but refuses to let them out again: it is a valve opening inwards only. The trapped ones die; their bodies decay and some of the residue is absorbed. No digestive fluid has been identified in this plant.

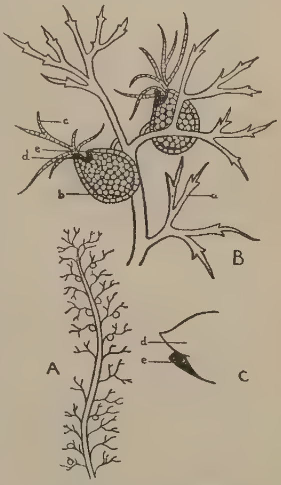


FIG. 53. BLADDERWORT

A, Plant, less than natural size; B, Magnified to show bladders; C, Valvular mouth of bladder.

a, branch; *b*, bladder; *c*, bristles; *d*, thin upper lip, a valve resting on *e*; *e*, thick unyielding lower lip.

In tropical swamps there exist some gorgeous plant fly-catchers. Brilliant colour attracts insects to them, ingenious devices of various kinds lead these into the digestive pot and keep them there. They are often to be seen in greenhouses and botanic gardens in this country. The best known are the *Pitcher Plants*; there are also trumpet-shaped *Sarracenias*, and the vice-like *Venus Fly-trap*. The apparatus in the latter is a leaf hinged along the midrib; when certain sensitive hairs on the leaf are touched by an insect, the halves fold together and their edges interlock. The fly is between them, and it stays there. After they have digested their meal, the leaf-lobes open out again and prepare for another.

CHAPTER XIII

THE PLANT AND THE SOIL

Agricultural research work in British centres pays great attention to the problems of the soil. Two volumes published by the Ministry of Agriculture are illuminating résumés of what is being done; they are *Agricultural Research and the Farmer*, and *Research and the Land*, both by V. E. Wilkins.

The Origin of Soil

A quarry face with an exposed section through soil overlying the rock, shows the transition from solid rock to surface soil. The top layers—the *soil*—are darker, looser and softer than the rest, and are full of short roots; below these is less friable material, with fewer roots—the *subsoil*. The subsoil grades down into rotten rock, from which it is largely derived. The property which distinguishes soil from disintegrating rock is the admixture of the dark residues of plants and animals in all stages of decay. This is the *humus* element of soil. The two classes of ingredient that go to make soil are:

(*a*) The mineral derivatives of rock.
(*b*) The organic derivatives of living things.

Ecological surveys must be based in part on the chemical character of the soil of the habitat. The underlying rock is not always a safe guide to that. In some places, the bulk of a soil is derived from that rock; but very often it has travelled far and may have a radically different composition. As a simple instance, the lower slopes of a hill may be of sandstone and yet be inhabited by plants which are known to be typically restricted to limestone soils. Analysis of the soils in which they are rooted shows that there is abundance of lime present; it is being brought from limestone beds higher up the hill by every fall of rain. A second example exists in the alluvial flats bordering rivers, which may be a rich mixture of soils from the whole catchment area of the river. Again, the British Isles are notoriously blanketed with "drift" left behind as muds and gravels by the glaciers of the Ice Age. Mud, sand, gravel, great boulders often travelled scores of miles from the beds to which they originally belonged; the Great Chalky Boulder Clay of parts of East England by no means always rests above chalk rocks. Soils with this history are referred to as *transported* soils; the first type, as *sedentary* soils.

THE SOLIDS OF THE SOIL

It is probably the physical character of the soil which dominates the vegetation which grows in it. The soil physicist classifies soils on the basis of the size of the soil particles. One of his classifications, in outline, is this:

Sand .	particles of 1 mm. to 0·05 mm.
Silt .	particles of 0·05 mm. to 0·005 mm.
Clay .	particles below 0·005 mm.

A loam is a mixture of sand and clay; a marl is a clayey loam which contains carbonate of lime in no higher proportion than ten per cent. (If lime is more than ten per cent of the whole soil it is termed *calcareous soil.*)

Mixed together in every variety of proportion, the soil particles of course never fit exactly. A maze of cavities pervades the mass of soil. The size of the mineral particles determines the *porosity* of the soil, and consequently its water capacity and its permeability to water. Amongst the fine grains of a clay soil the channels become hair-like, so small, indeed, that they give rise to the effects characteristic of *capillary tubes*. The sum total of these spaces, the *pore space*, is very great in a clay soil; it may reach fifty per cent of the whole volume. The surfaces bounding such a network will also be great, and therefore high frictional resistance would be offered to liquids moving through it. The great total space results indirectly from the smallness of the particles; they are so light that they do not readily arrange themselves compactly.

In soils with a high percentage of sand the individual spaces are much larger and may be even too great for capillary forces to come into play. The total pore space, on the other hand, decreases as the size of the particles increases, for they settle themselves close together; in coarse sand it may be no more than twenty-five per cent. Percolation through such sand will go on freely, but the amount of water which it is capable of holding will be low. A sandy soil may be rendered difficult of penetration by the presence of even a small amount of clay particles, which will pack into the spaces between the sand particles.

The mineral particles stand for the less soluble residues of rocks of all degrees of acidity. They may undergo further changes in the soil. They may supply part of the plant food when they go into solution, or they may be of such a nature as to render the soil unfit for plant habitation. In sandy soils, silica usually predominates; in clay, silicates. Calcareous soils (chalk and limestone) form a very distinct type; the percentage of carbonate of lime in them may reach sixty per cent. In the presence of water and CO_2, part of the carbonate is converted into bicarbonate and goes into the soil solution.

The question of size of particle affects the soil condition in a way which was not fully realised until recently. It is supremely important and requires special effort to understand it. There is, however, a simple way of demonstrating its action. Shake up some clay soil in a tall glass jar and allow it to settle. Most of it soon collects as sediment at the bottom of the jar; but for a very long time (weeks) the water remains faintly hazy with clay matter so fine that its particles are not recognisable. Matter reduced to this microscopically minute condition is said to be in a *colloid condition.* Sometimes the substances are spoken of as *soil colloids*, but they must not be mistaken for new substances. They are the known substances—clay and humus, for instance—which have assumed and retained this peculiar character of extremely fine division, without going so far in disintegration as to reach that molecular division which is expressed by saying that they are in solution. In a clay soil, in which the action of colloidal matter is most strikingly manifested, it exists as a jelly-like coating of the particles, part of its substance derived from the clay itself and part from organic matter in the soil. This double origin of the soil colloid is important. If you add a little lime to your glass with its colloidal clay, you will see the water clear up quickly. The lime causes the colloidal units to collect in groups; these groups are heavy enough to sink more quickly; this is known as *flocculation*. When the agent of flocculation is removed (there are others than lime), the original properties of the colloid reappear; the clay is said to be *de-flocculated.*

The properties of a colloidal substance are very striking; the following are outstanding:

(*a*) One has already been noted—when the colloid is put into water, its particles remain suspended for a very long period; a trace of acids or salts added to the water causes flocculation of the particles. According to one promising theory, every one of the particles bears a charge of electricity; the charges are all of the same kind, either positive or negative, and according to a law of electricity the bodies bearing them repel each other. This would account for their aversion to settling down together. The introduction of a substance bearing an opposite charge, which changed the electrical conditions, would be followed by mutual attractions into groups (flocculation).

(*b*) A colloid can attract water to itself and hold it firmly. There is in this no true chemical union; the water is thought of as a precipitate on the surface of the particle; it is then said to be in a state of *adsorption*.

(*c*) Similarly, the colloid particle can withdraw various substances from solutions, and even break down salts, the bases set free from which it attaches to itself, whilst the acid radicle remains free. This is another instance of adsorption.

(*d*) Sometimes the colloidal matter passes into a jelly-like condition known as a *gel*, in which other properties develop.

The vast importance of the existence within the soil of clay and humus as colloid bodies will be apparent. It means that vitally necessary water and salts may be retained by this "adsorptive" clutch when otherwise they might disappear quickly in the drainage-waters.

We note, then, that clay or humus consists of a mass of *compound particles*, i.e. the *ultimate* or original particle together with its coating of adsorbed substances—water and such as silica, alumina, alkaline bases, etc. Any agency destroying the colloid condition breaks down these compound particles and lessens the food-value of the soil. They may take a long time to rebuild.

Humic acids, as products of decomposition in peaty soils, are no longer recognised by the botanist. Neither is humus as a single identifiable substance; it is a complex, in a colloid condition, of a number of substances. It seems to have been proved that the acid reaction shown on the application of litmus paper to a peat soil can be accounted for by assuming that the colloid humus withdraws the base from the salt of the litmus paper, leaving the acid radicle which, of course, gives the red coloration, precisely as would happen if a humic or humus acid had existed in the soil.

It must be remembered that apart from those peaty soils with an acid reputation there are, certainly, acid soils which owe their acidity to mineral acids.

The Soil Solution

Water exists in the soil in more than one condition.

(*a*) Every particle having the dimensions of those of clay has the power of retaining round it a film of water, this film being held fast in place by the force of *surface tension*. This is a force which attracts the water molecules one to another, tends to crowd them into the smallest space possible, and acts more strongly inwards at a free surface. In a water-film on a particle, the force increases with the curvature and hence with the decrease in size of the particle. When particles come into contact, their films coalesce where they touch, and the thinner the films the narrower the triangular spaces adjacent to the points of union. The narrow spaces are tube-like, and the finer their bore the more powerful is the *capillary* (surface tension) *force* which they maintain. Differences in the thickness of films which are in communication will induce movement of water, the higher tension force in the thinner films attracting water particles from the thicker films. The film-water is often referred to as *capillary-water*. Evaporation from the surface of the soil may be so severe that the films on soil particles in the upper layers may grow so thin that the water particles cannot be held together; the film ruptures and disappears. Such soil is said to be air-dry; there is still some water present in it in the form of vapour in the soil air.

(*b*) When the surface films attain a certain thickness they cease to increase. Unless the pore spaces are of the smallest order, there will be left unfilled space. Further additions to the water in the soil will occupy these spaces as *free water*. The force of gravity will urge this free water downwards and it will collect when it reaches an impermeable rock layer. The saturated condition is reached when the spaces remain filled with water; the upper level of such rock or soil is known as the *ground-water level* or the *water-table*; it will be the level at which water stands in wells.

(*c*) To the above may be added the *adsorption-water*, which the colloids covering a clay particle bind so closely there.

The water within the soil is made to move in all directions by forces which are often in conflict among themselves. The force of gravity is compelling it downwards all the time. Trace the course of the rain-water; some runs off the surface, some evaporates, some probably gains entry to the soil where it falls. If the upper layers of a close-grained soil (e.g. clay) are air-dry, the pores will be filled with air and the first rain which falls will have great difficulty in making an entry and forming films; this is why light summer rains after drought are of such slight service to plants. Flooding drives the air out; then the water moves downward; the rate of percolation will depend on the size of the pore spaces. In a fine clay, the frictional resistance offered by the walls of the narrow channels hinders the progress of the water; this is one reason a clay soil retains water longer than a sandy soil, in which the total wall-surface is less. The rain-water may penetrate deeply enough to join the ground-water mentioned above; this underground tank draws its contents partly from the rainfall of the locality, and partly from water which has travelled down subterranean slopes lying above impermeable beds; the second source accounts for the occurrence of wells in deserts. A stage is possible when the whole of the pore space in the soil is filled with water; if such a condition becomes permanent, as in the soil of marshland, the soil is said to be *water-logged.*

There may also be movement in the opposite direction, upwards, and possibly starting from the water-table. Evaporation tends to reduce the water-films near the surface. As a film is reduced the resulting tendency will be for water particles to move towards it from the thicker films at lower levels. This will act successively in lower strata till communication with the ground-water may be established. The idea that capillary action would raise water through considerable distances has been much modified as the result of recent experiments; the water-table must be pretty near the surface before a direct flow can be established between it and the surface layers.

A third factor enters into the question of water movement when root-hairs are absorbing moisture from the soil. Every absorbing root disturbs the equilibrium by lessening the amount of film-water in its vicinity. Here appears again the importance of the size of the spaces. If they are small, the tensions will be great, but the friction also will be great. According as one or the other prevails, the water needed by the plant will or will not be brought up to the root-hairs with sufficient rapidity to supply the plant's needs. It is possible for plants to perish from drought even in soils containing a fair amount of water, if that water cannot travel quickly. In a sandy soil, on the other hand, death from drought would be due to the low capacity of the soil for moisture.

When soil colloids are present, their power of attraction for water has to be added to the list of influences which are acting on the soil solution.

The plant's root-hairs are lying in close contact with the soil particles and are drawing their supplies from the water-films. Against them are acting surface tensions and colloidal attractions, becoming more powerful as the films grow thinner. A point may be reached when the plant fails to overcome the opposition, and it may suffer water famine with water close to it.

We see, acting and counteracting within the soil, gravitational force, surface-tension forces, colloidal agencies, and the osmotic relation of the cell sap to the soil solution. It is a condition of trembling equilibrium, or rather, of passage from one equilibrium to another.

To summarise a little:

A soil's *water capacity* measures the amount of water which could be held within it in any manner without causing swelling. It depends on the total volume of the spaces which surround the ultimate particles: it may include free water in spaces, film-water, adsorption-water. It is very high in soil with much clay and silt; low in sand and gravel.

A soil's *retentive power* measures its ability to *hold* water within its structure. Resistance due to narrow spaces is in favour of it; high surface tensions act in the same way; colloidal adsorptive power, which is, like the surface tensions, associated with a fine state of division, has the same effect. It will be seen then that clays, and soils with much humus in them, have a high retentive power, whilst sands and coarser silts have a low.

Permeability of soil refers to the facility with which water moves through it, either as free water of percolation or as film-water. It is greatest when the pores are widest, e.g. in sand.

The available soil-water is that which the plant is able to abstract from the soil.

EXPERIMENTS ON SOIL

Experiment 1. *Mechanical estimate.*—This method gives only a general idea of soil constituents. Place in a tall glass vessel a handful of field soil which has been dried. Fill the vessel nearly full of water; shake up well and leave to settle. The particles take up positions roughly graded in layers; any pebbles present lie at the bottom, then comes sand, then clay. If vegetable matter, including humus, is present, it may be floating as larger pieces at the surface or resting as a dark-coloured layer on the clay.

Experiment 2. *Percolation through soils.*—The apparatus consists of large funnels lined with filter paper and fixed to retort stands; a receiving vessel is placed under each. In one, place dry garden soil rubbed loose; in the second, sand; and in the third, powdered clay. Pour into the funnel over each an equal quantity of water. Note the time which elapses before the first drop escapes from each funnel, and the time before percolation ceases. Measure the total amount of water which passes through, and reckon from this the amount which has been retained. The action of humus may be shown by placing in one of four funnels pure sand, and in the other three the same sand mixed with humus in increasing proportions. A very direct relation between the amount of humus and the rate of percolation will be apparent.

Experiment 3. *Capillarity in fine tubes.*—Take four glass tubes differing in bore, ranging from about a quarter of an inch to fine capillary dimensions. Set them up, supported by retort stands, with their lower ends dipping into dishes of red ink. Note the height to which the liquid rises in each; it will be highest in that of smallest bore, lowest in that of greatest bore.

Experiment 4. *Capillarity in soils.*—This tests the systems of capillary tubes within soils. Compare as many as are available, including a sandy soil, a clay soil, a good garden loam, and a soil containing excess of humus. Dry the samples. Prepare tall glass cylinders (one inch wide and at least eighteen high); fix a piece of muslin over one end of the cylinder. In these place the soils, shaking them gently into place. Set the tubes with the muslin dipping into dishes of water. Make careful note of the time when this is done. The water will rise in the soils at different rates. Observations must be made frequently, and the level to which the water has risen be recorded by a mark on the cylinders. The records will have to extend over several days. A few seeds may be placed on the top of the soil and their germination dates noted. The comparative capillary power of the soils can be deduced from the results.

Experiment 5. *Humus in soil.*—A dark-brown or blackish colour is usually an indication that humus is present in soil; so also is low weight. Its presence may be tested by a method applied beforehand as a preliminary to dry leaves or bits of wood. Arrange a tube so that its contents can be heated whilst at the same time a current of air is drawn through the tube and passed by a delivery tube into and through a jar of lime-water. Place in the tube dark soil suspected of containing humus. Heat it strongly. If humus is abundant the dark colour gives place to red or yellow; the lime-water becomes milky. Carbon dioxide has passed into it, and this is the product of the combustion of the organic material in the soil.

The soil-water holds many substances in solution, and one of the problems of agricultural research is to determine which of them are lost in drainage-water and how to save them. Such waters usually contain sulphates and chlorides of calcium and sodium, and may have much calcium bicarbonate. Ammonia, phosphoric acid and potash are probably held fast by the soil in colloidal unions; there are only traces of them in the drainage. Heavy loss of nitrates has, until recently, been considered to be usual; results of recent experiments in Aberdeen, however, indicate that it is much less than has been supposed.

The soil solution of land which is in a fertile state is neutral or slightly alkaline to litmus paper. Growth is generally poor in soils which exhibit an acid reaction. Sometimes acidity is due to mineral acids; sometimes it indicates the presence of colloids.

THE SOIL ATMOSPHERE

There are two atmospheres in the soil. The air in the spaces in the surface soil differs only slightly from the atmosphere above; the percentages of carbon dioxide and nitrogen are a little higher.

The second atmosphere is in solution in the water of the soil-films; it is almost devoid of oxygen; ninety per cent is carbon dioxide, and the rest nitrogen. It maintains the anaerobic bacteria (p. 153).

THE SOIL TEMPERATURE

The vital processes of the plant roots and of the soil bacteria require a certain minimum temperature and are carried out best at a certain optimum. The minimum for both in north temperate zones is about 41° F., and the optimum about 99° F. Very low temperatures check, in particular, the nitrifying bacteria. This is the cause of the yellowing of young crops when the ground is chilled; they are suffering from nitrogen starvation. The agriculturist assists spring growth by adding nitrates as manures.

Temperature will vary with depth; surface layers will experience greater diurnal variations than those lower; the depth affected by such variations is never more than three feet, and they are only very marked and rapid within the top few inches. During the day the surface-soil temperature is much higher than the air temperature. Below nine inches the soil is generally a little cooler than the air in summer and warmer in winter.

Clays heat much more slowly than sands; this is chiefly because they hold much more water, and the water requires five times as much heat to raise its temperature as does solid soil. This high specific heat implies also that cooling will be slow, as the heat stored is so great. However, there must also be taken into account the fact that evaporation of the water may rob the soil of heat in order to effect the change of state from liquid to vapour. Humus, being a powerful water-retainer, acts like clay. The amount of sun-heat absorbed will be raised in the case of dark-coloured soils.

THE SOIL ORGANISMS

The soil maintains within itself a swarming population. In many vital ways these micro-organisms are bound up with the existence of the massive plants, parts of which share the soil with them. It is a mixed assemblage of plants and animals; they furnish the *biotic* factors which we consider in connection with a plant's habitat.

Rabbits, Moles, Earthworms, by their burrowing, loosen the soil and admit air into it. Millipedes, Centipedes, Beetles, etc., feed in it, die in it and decay in it. The larvæ of many aerial creatures are harboured in it. These are all of consequence, but we are specially concerned at present with the microscopic organisms, whose doings are so difficult to follow but of which we are not likely to overestimate the value.

Protozoa are microscopic one-celled animals. They are said to be able to move about in the soil. There are myriads of them, yet for long their very existence was unsuspected. Now, however, they, along with bacteria, are accorded immense attention. Rothamsted breeds them, counts them in their millions, classifies them, watches their ways of living. The workers there tell us that one gramme of soil may contain 45,000,000 bacteria and 1,000,000 protozoa. Protozoa feed exclusively on bacteria, and they keep the bacterial population within bounds. On the other hand, some bacteria seem to do their work of forming nitrates better when protozoa are present, perhaps by feeding on the dead protozoa. Soil can be freed from protozoa whilst retaining its bacteria, by raising it to a certain known temperature; protozoa are more readily killed by high temperatures, or by very low, than are bacteria.

Bacteria, or "germs," are the most infinitesimally small of living things. Their colourless single cell may have many shapes—sphere, rod, comma, spiral, etc. They multiply at a tremendous rate, two individuals coming into existence simply by the splitting across of one. They are so small that there is little information about their internal character which can be depended upon. Some can withstand temperatures below freezing, some live in hot springs. They may go into a thick-walled resting stage as spores; these are still more resistant, boiling for an hour failing to kill some of them.

Classified according to air requirements there are two groups of bacteria in the soil. The *aerobic* bacteria respire in the usual way, demanding oxygen; the *anaerobic* bacteria can live without oxygen—in fact, it kills them. Life in the soil is only possible for the anaerobic species in two situations; first, they may live in the water-films enveloping the soil particles, the atmosphere in which is devoid of oxygen; second, they can exist in the ordinary atmosphere of the soil spaces if they can have as near neighbours bacteria which will use up all the oxygen there.

The presence of aerobic micro-organisms in the soil can be detected through a product of their respiration. Place some good garden soil in a well-corked flask. Fit into the cork, (*a*) a glass tube to admit air, (*b*) a glass tube which is carried into a jar of lime-water. After a time calcium carbonate appears in the lime-water. The carbon dioxide which has united with the lime to form this has been given off in respiration by the soil organisms. To prove this, carry out alongside the other a control experiment. In this the soil must have been treated in such a way that its population is likely to be killed. This may be done by raising it to a very high temperature, three or four times, at intervals of several hours, keeping it in a closed flask.

Nitrifying Bacteria. A plant or an animal dies and the remains mingle with the soil. At once the dead matter is attacked by hordes of greedy creatures, amongst them bacteria. Sugars, starches, proteins are all broken down. At the end of one set of changes, ammonia (NH_3) appears as a product. Some of this is lost into the air; some forms compounds with substances present in the soil, e.g. ammonium carbonate. Upon ammonia in these various forms certain bacteria depend for energy; they induce the nitrogen of the ammonia to unite with oxygen, in which process, of course, energy is liberated. The proportion in which the two elements unite is that found in nitrous acid, HNO_2; this may unite with bases from the soil and form nitrites of soda, lime, etc. The bacterial specialist which does this work is a little round thing called *Nitrosomonas* (Fig. 54). Then the rod-like *Nitrobacter* comes into action. By causing further oxidation it changes HNO_2 into HNO_3 (nitric acid), or changes nitrites into nitrates. The above outlines one side of the life of these two groups of bacteria, but there is another. They must build up protoplasm for themselves; the carbon for this they get from carbon dioxide; to live and work they demand certain conditions—the soil must be well aerated, for they are aerobes; they must have moisture and they must have a soil temperature about the same as that needed by root-hairs; they must have carbon dioxide in the form of carbonates, and there must be extremely little organic matter in contact with them (cf. p. 158). A very simple experiment will demonstrate the presence of nitrate-forming bacteria in soil. Fill a long glass tube with garden soil: arrange that dilute manure-water should pass slowly through the soil. The water when it enters contains ammonia, but only a small amount of organic nitrogen compounds; after its passage through the soil its ammonia is replaced by nitrates.

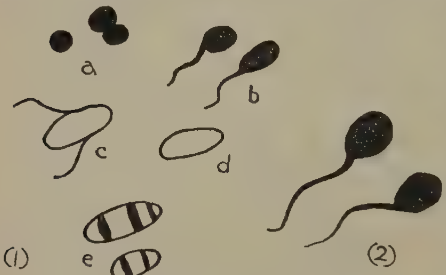


FIG. 54. BACTERIA

(1) *Bacillus radicicola*; (2) *Nitrosomonas*. *a–e*, forms which the bacillus may successively assume.

The organic matter in the soil is known in a general way as *humus*; this is a complicated and variable substance about which statements have to be made very carefully, for of both its exact origin and its nature our knowledge is small. Its source is the carbonaceous part of plants, that seems certain. It seems clear, too, that in nature the processes by which the organic remains are transformed into humus are the work of bacteria and fungi. They are regarded as falling into two stages. The anaerobic bacteria accomplish the first; they can work in the absence of air. If aeration is bad (and in other conditions), the processes stop at this stage and what is known as "acid humus" collects; this is harmful to most plants. If the conditions required for the aerobic group of bacteria are fulfilled, the second stage of change is entered upon, and "mild humus" results; this is most valuable for plant-growth.

Denitrifying Bacteria. These act in a manner the reverse of the nitrifying bacteria. They are anaerobes, and find very congenial the heap of slowly decomposing plant matter. They break down ammonia and nitrates; the nitrogen so freed escapes into the air.

Nitrogen-fixing Bacteria. These are, you might say, the life-savers of the world. Plants must have nitrogen. Normally they get it from the soil, where it exists as compounds of ammonia and as nitrates. These are inorganic, but they are not derived from the mineral constituents of rocks. We have just seen how some of them are derived from dead organic matter. But again, where did that get its nitrogen? Is there any other source? Our thoughts naturally turn to the vast stock of nitrogen in the atmosphere—seventy-nine per cent of the whole; plants are bathed in it, but, as a simple experiment (p. 133) shows, they are powerless to utilise it.

Given free nitrogen and oxygen and an agent which can induce them to unite, the soil would furnish the salts of sodium, potassium, etc., necessary to yield bases for nitrates. As far as we know, nitrogen and oxygen unite under compulsion from only two agents—a flash of lightning and bacteria! During a thunderstorm, electricity causes a union of the oxygen and the nitrogen of the air, and nitrous and nitric acids are formed; the characteristic smell may be noticed in a tub of rain-water collected in a thunderstorm. This hint of nature has been acted on by man; he now makes on a large scale by the use of electricity nitrates and compounds of ammonia which can be used as manures.

Certain bacteria, living free in soil and water, wielding the power of electricity in this particular, *somehow*, compel nitrogen and oxygen to unite, and from these plus bases nitrates are formed. *Azotobacter* is one of them; it is not present in all soils, even some which are promising; it must have good air, moisture, moderate temperature, calcium carbonate and carbohydrates. *Clostrydium Pasteurianum* is an anaerobe; it lives in company with two aerobes. It breaks down the bodies of dead soil algæ and uses the energy set free for building up nitrogen compounds.

Other species of nitrogen-fixing bacteria have found more comfortable quarters than the soil; they find rooms in root tissues. Recall the nodules on the roots of the Broad Bean (p. 5). Such swellings are common to nearly all members of the Family of the Leguminosæ, and also to Alder, Bog Myrtle and some other plants.

They have an interesting history. When the seedling of the plant was very young, there slipped through the walls of its root-hairs some individuals of a particular species of bacteria which was lurking in the soil. By name, these little rod-shaped germs are *Pseudomonas radicicola* or *Bacillus radicicola* (Fig. 54). Once inside the cell they throve at a great rate. The cell sap gave them sugar; the air diffusing into the cell gave them oxygen. From the sugar they took carbon; carbon and oxygen united; they appropriated the energy thus liberated. But by virtue of their special powers they did more. They used as food the nitrogen which was also circulating among the cells and made that enter into organic combinations. In *that* lies the triumphant achievement of these bacteria. Atmospheric nitrogen is deprived of its freedom; it is *fixed* in nitrates or in the more complex form of protein. Part of it at least becomes protoplasm in the bacterial cell, which grows and divides; part may go direct to the tissues of the root.

This speck, which requires a powerful microscope to make it visible, has done its share towards augmenting the food-stocks of the world. Its brood passes inwards from cell to cell of the little root, taking and giving. Their presence stimulates the cells to abnormal growth, and the combined increase gives the nodule. The dead bacteria, lying within the cells, constitute ready-made nitrogenous food for the plant. It is also possible that the plant destroys bacteria and absorbs them. This special food-supply makes plants favoured with these bacterial guests largely independent of the nitrogen content of the soils in which they grow. When the host plant dies in autumn the nodules decay. Such dead bacteria as they contain are added to the soil-stock of food; they break down in the usual way. The live bacteria are set free in the soil. There they stay, still breeding and dying, till fresh roots offer themselves in a new season. A crop which is fed partially through these bacteria leaves the ground richer in nitrogenous plant food than it found it; this is due partly to that which is derived from the nodules themselves, and partly to the general bulk of the plant substance if that is allowed to stay on the land. It is this fact which leads the farmer to put Clovers or Beans and Peas into his rotation of crops, the Clover to follow a grain crop which had greatly impoverised the soil. Large areas of poor sandy soil have been rendered fit for cultivation by treating them with manures and sowing them with leguminous crops, e.g. Lupins. In trying to extend the production of Lucerne in England, a curious fact was illustrated. It refused to grow in many places, the reason being that the soils there hold none of the bacteria which Lucerne favours. The Bean bacteria are abundant there, as they are nearly everywhere, but they are of no service to Lucerne; its taste in bacteria is exclusive. The

Plant Research Stations are now breeding and distributing its special germ, with which farmers may inoculate the soil.

In these connections an interesting variation may be made on your culture experiments (p. 132).

(*a*) Set up a sand culture in which sand and plant-pot have been thoroughly sterilised; plant in it Pea or Bean seedlings which have never been in soil; water as usual with normal culture solution.

(*b*) Proceed exactly as in (*a*), except that you add to the culture solution a grain or two of garden soil. Nodules will form on the roots in (*b*), but not in (*a*).

Fungi. The part played by the *micro-fungi* in the soil is not as well known as that of the bacteria. Very likely some of them share in the processes of breaking down organic compounds and freeing ammonia. There are cases in which fungi, like the bacteria of the nodules, are considered to " fix " nitrogen from the air. Many plant diseases are caused by fungi, e.g. wart disease in Potatoes; this may be compared with similar functions of bacteria, e.g. in some " rots " of Turnips.

Fungi working in partnership with higher plants, in the symbiotic form of mycorhiza, are noticed on page 140.

Types of Soils

The cultivator can improve soil by digging or ploughing. He thereby makes it easier for roots to penetrate, admits air, distributes food material and, if at times he breaks into the subsoil, adds some of that to the soil, which is thus deepened. To certain soils he applies definite remedies to secure good physical conditions.

Clay Soils. These offer great resistance to the entrance and passage of water; their pore capacity is great and they are highly retentive, but liable to become water-logged. They tend to be cold, and discouraging to spring growth; they are not well aerated. They tend to shrink and crack in drying, forming hard lumps. They are usually poor in calcium carbonate, but rich in some soluble mineral salts. Research is proceeding to find what type of farm implement can best overcome the great resistance of these cohesive soils. Lime is added to heavy clay land in order to lighten it; this it does by flocculating the colloidal clay, when the soil particles fall more readily apart. Lime corrects the tendency to "sourness." Stable manure, when well mixed in, renders the soil texture freer; its decay somewhat raises the temperature of the soil. Sand may also be added to garden soil which is too heavy; when possible, clay may be improved by burning it.

Sandy Soils. These are well drained; their water capacity is small; their retentivity is low. They are easily heated and quickly cooled. In this country they are often deficient in calcium carbonate; they also contain little plant food such as potash. They are improved by the addition of vegetable matter, either in the form of stable manure, or as green manure—for example, leguminous crops sown and ploughed in. These add plant food, and enable the soil to retain water better.

Calcareous Soils. Soils containing five to sixty per cent of calcium carbonate bear distinct types of vegetation. Unless very thin, they are very favourable to plants. They are warm and dry, and are well supplied with soluble salts. The soil solution is neutral or alkaline; it suits the nitrifying bacteria and earthworms; direct poisoning of the plant by acids is averted. Plants which belong exclusively (or nearly so) to calcareous soils are termed *calcicoles*; *calcifuges* are those which avoid limestone. The effect of lime on these plants may not be directly chemical. Some botanists consider that excess of lime disturbs mycorhizal fungal growth and over-stimulates bacterial growth, with the result that such plants as Heather, which depend on the fungi, are absent from limestone soils. Others think that the function of the calcium carbonate is to keep the soil solution at constant strength, notwithstanding variations in the amount of water present.

Peat Soil. Peat is a compact mass of slowly decomposing plant tissues. If there is a stoppage at the end of the first stage in the series of decomposition changes (p. 154), peat stands as the result. Some of the causes suggested for such a stoppage are: a temperature too low for bacteria to act, the presence of so much water that air is excluded, the absence of calcium carbonate (necessary for the bacteria concerned in the second stage), the accumulation of poisonous by-products due to the activities of the bacteria themselves. The last is the foundation of the most recent theory. Peat contains little potash or phosphates; its soluble nitrates are scanty; the drainage-waters are acid.

Acid Soils. Acidity has proved to be a difficult section of soil studies; but a recent discovery about acid soils seems to promise substantial help in treating them; generally they are infertile. The rule which has hitherto been a rough guide is that a "sour" soil, one which turns blue litmus red, may have its acidity counteracted by the addition of lime. It has long been a puzzle that extensive areas in Scotland, North Wales and Ulster give an acid reaction in their soils and yet are very fertile; the addition of lime there results in little or no increase in fertility. These soils have one character in common; they are derived from the oldest rocks of the British Isles (many of them igneous), the crystals of which are little altered from their original condition. Over a great part of England the soils are formed from rocks of Secondary and Tertiary Age; the particles have been altered over and over again by weathering since the time when they formed part of the old rocks mentioned above. In the old rock, crystals hold great stores of bases other than lime (e.g. soda) which evidently plants can use for some purposes instead of lime; further, though calcium carbonate is not present, calcium occurs in the form of other calcium compounds, and is gradually set free. The vital question about a soil is not its poverty in lime, but its poverty in the group of " exchangeable bases," calcium, magnesium, potassium and sodium.

CHAPTER XIV

THE LIFE-HISTORY OF THE COLTSFOOT

Tussilago Farfara (Linn.)

A PLANT of common occurrence, of striking appearance and possessing properties which attracted the attention of the early physicians, the Coltsfoot has a fairly long historical record. It has had many names. A group of them, derived from the resemblance of the leaf to a hoof, includes Coltsfoot, Foalfoot, Fillyfoot, etc. In the north of England *Cleet* means hoof, and the decoction made from the flowers is known as *Cleeats* beer or *Clayt* wine. Because the plant has been considered partial to clay soils it has been called Clayweed. In Cumberland, it is Clatter-clogs, and in Caithness, Dovedock; in Mid-Scotland, the name Son-before-the-father (i.e. flowers before leaves) may be heard. Its Latin name comes from *tussis*, a cough (decoctions for the cure of coughs are still made from its flowers and leaves), and *Farfara*, the White Poplar, the leaves of which it resembles. English corruptions of *Tussilago* are Dishalago, Tushy-lucky, etc. Amongst other things which Pliny says about it is that the Greeks called it Asarum (Greek *a*, not, and *sairo*, I adorn), because its use in chaplets was forbidden. The physicians of the sixteenth and seventeenth centuries evidently made great use of it. In Gerard's illustrated herbal two pictures are given; one is of the plant in bloom, labelled *Tussilago florens*, and the other of the leafy condition, named *Tussilaginis folia*.

Pliny describes the summer plant and thinks it has no flowers. "It beareth leaves like Ivy, but somewhat bigger, either five or seven in number, which underneath or toward the ground be whitish, but above in the upper side of a pale colour, without flower, stem or seed, and the root is small." His contemporaries seem to have made of it a kind of divining-rod: "Wheresoever it is seen to grow it showeth that there is water under it—a thing that they know well who seek for springs: for they take it to be an assured sign and direction to water." Dodoens, the herbalist, says that the green leaves pounded with honey cure "the hot inflammation called St. Anthony's Fire, and all other kinds of inflammation." Also, "The green and fresh leaves are moist, but when they are dry they become sharp or sour, and therefore are of a drying nature. . . . The perfume of the dried leaves laid upon quick coal, taken into the mouth through the pipe of a funnel or tunnel, helpeth such as are troubled with the shortness of wind." Pliny's version of this prescription has, "but between every pipe you must sip a pretty draught of sweet wine." To-day we find Yorkshire children clearing the banks of their golden blossoms that Yorkshire mothers may brew a draught which may not be quite as palatable as sweet wine. Parkinson (1640) mentions the preparation of tinder from the "roots" of Coltsfoot.

Coltsfoot in its Homes

It has many homes. Even in the centre of the smokiest of cities it maintains itself on corners of waste ground, so that the city child may easily follow its yearly progress. It is a plant which carries on so great a part of its life underground that we may usefully investigate at once what is underground. Begin the examination in autumn, when the mature structures of the current year and the resting buds of the following year are to be seen in their relative positions. Any one of the independent-looking plants in the Coltsfoot bed includes a clump of heavy green leaves crowded on the summit of a short upright stem, of which no more than two inches is visible. If access can be got to an embankment on which the surface soil is rather loose, it will be fairly easy to lay bare the buried parts of the Coltsfoot colony. Remove the soil carefully, layer by layer. The leaf-bearing stems are seen to continue downwards for varying distances, tapering off into thin pipe-like forms. From the upright stem (for which the term "basal" is useful) branch off many of quite different character; they are root-like, but are branches. Through and through the soil run these long slender *rhizomes*, branching freely, directing their tips first in one direction then in another, travelling many feet from their starting-point, and always somewhere or other sending up to the surface a shoot the bud-tip of which is to be converted into a new basal stem. So complicated is the subterranean network that it is usually impossible to identify the parent or parents of the colony.

As an ecological exercise, one might try to find out how Coltsfoot behaves as a colonist and in what places a plant with this communal habit is able to establish itself.

Coltsfoot is often spoken of as a clay-loving plant; probably it is not the chemical character of a clay soil but its high water content which is favourable. Light sandy soils and coarse grits are usually too dry, although the spoil-heap of a sandstone quarry may be covered with Coltsfoot bearing exceptionally handsome flowers. In a case like that, the rhizomes and roots are getting at water at a considerable depth. On thin soils over limestone, Coltsfoot is absent, because such a soil is too dry. The presence of lime in the soil is not harmful, for plants grow on the wet margins of streams flowing over limestone and even in water-washed crevices of limestone rock. It does not object to heavy red clay containing much iron. The boulder-clay cliffs of Yorkshire, exposed to the dash of salt spray, support great patches of it. Chemically considered, then, its taste seems to be fairly comprehensive.

Coltsfoot must have a regular and plentiful supply of water, but drainage must also be good. The marsh is not its home, though it may be found with its branches dipping into the stream. A very dry spring means late and poor flowering. Notice the astonishing rate at which plants indoors absorb water when flower-stalks are lengthening.

Coltsfoot is not a shade plant. It will grow profusely right up to the edge of the wood; within the wood, not a single plant. The sunny side of a railway embankment or cutting always has a much finer and earlier display of blossom than the shady side.

In its association with other plants Coltsfoot is interesting. Its fruits travel far and wide (p. 171). Its seedlings are amongst the first to settle on broken ground. On a roadside, it gets its runners embedded along the margins of the ditch or on loose mounds of soil, but it does not penetrate far into the grassy verge. It can keep its place on crumbly banks where grass fails, and ends there by binding the soil together.

It has few associates: its broad leaves check all other growth near to it. Only occasionally does it live alongside Grasses of freer habit; in the Grass sward it is replaced by its relation the Dandelion, whose long tap-roots can compete better with the Grasses than can the spreading rhizomes of Coltsfoot. One of the common habitats is the railway embankment; on the high slope with its originally open surface, the seeds would find favourable nooks in which to germinate, and the first rhizomes an easy soil to penetrate.

Coltsfoot which has got a footing is not easily exterminated, as you may find in garden experiments. To remove it by digging, every node must be cast out. Draining the ground may starve it out; by cutting off every leaf as it appears, it may, in time, be made to die of carbon starvation.

THE RHIZOMES AND THEIR HISTORY

The two types of rhizome are seen in the autumn plant illustrated in Fig. 55. The upright "basal" organs are stems with very short internodes. Within the strong, clasping base of each one of the crown of leaves, and above the scars of leaves which have fallen, stand upright groups of buds—usually three in a group; these are chiefly buds of next year's flowering axes. The rhizome-buds of the next year are slim and pointed, and stand at right angles to the axis at lower levels usually than the flower-buds; occasionally the central bud of a trio is a rhizome-bud.

The travelling rhizomes are white, tough and flexible; they can drive through close soils. So far-reaching are their ramifications, and so long do they remain intact, that dozens of plants scattered over a broad bank may all be derived from one original plant. In September, most of the rhizomes which originated in summer grow parallel with the surface of the ground. The nodes bear pale-yellow scale-leaves. Adventitious roots grow from both basal and rhizomic branches. Rhizomes which begin their growth at the end of autumn direct their tips almost straight downwards.

The winter resting state lasts only a short time. In late autumn the leaves shrivel and rot; this leaves the buds naked on the axis; in winter the apex of the axis nearly always decays. Very many buds perish during the winter; some are saved because they are covered with soil; some are sheltered by the fragments of old leaves. All exposed to light are dull purple; those hidden are yellow or yellowish green.

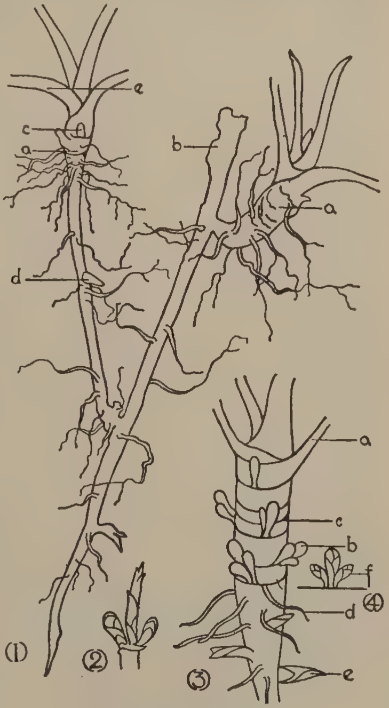


FIG. 55. COLTSFOOT

(1) Rhizomes in August.
a, basal region which has filled during current year; *b*, decayed basal region of previous year; *c*, flower-bud for next year; *d*, rhizome-bud; *e*, petiole.
(2) Bud-cluster with central rhizome-bud.
(3) Basal region in October.
a, petiole; *b*, group of flower-buds; *c*, leaf-scar; *d*, root; *e*, rhizome-bud.
(4) Trio of buds.
f, scales.

The rhizomes are in active growth before spring sets in above the ground. As soon as the soil grows a little warmer, the new rhizomes appear; their angle of branching is acute and their tips grow upwards. Compare this with the horizontal direction in the summer rhizomes and the downward direction in the late autumn (possibly winter) rhizomes; can you suggest a reason? Before the storms of winter are over, the buds are venturing out from their winter quarters. March sees both flower- and foliage-buds stirring; but the flower-buds shoot far ahead almost at once. Throughout March and April they are swelling into full brilliance; by mid-May their fruits are ripened and scattered, and their work is done. Much slower is the progress of the leaves. Whilst blossoming is at its height, they are still bundled up in fleecy down. Not till May, at the earliest, do they attain full size. Their task of assimilation is fulfilled in the long days of summer. Much of the sugar they manufacture is sent down to the short upright stem. There it is stored up, the visible sign of which is the great increase in thickness. This is the origin of the " basal " stem. It is not of sugar that you will find accumulations in this storage structure. The sugar has been changed into inulin, with which you have already made acquaintance in the Bluebell. You might test various parts of the Coltsfoot plant for inulin at different times of the year. You may find out that the quantity of inulin in stock in the swollen upright stem is at its greatest in winter, and diminishes in spring; that inulin occurs in the leaf-blade and in the petiole at the end of the year: and that it never occurs in roots, in the thin upright part of the stock or in the long rhizomes.

With Coltsfoot rhizomes may be compared various others, e.g. Couch Grass, with numerous scale-leaves; Solomon's Seal, with very short, thick, prostrate internodes; Toothwort (p. 138), whose stems are concealed under fleshy scales. The aerial axes of Wood Sorrel arise from lateral buds on the rhizome, the apical bud of which carries on the horizontal stem (*monopodial rhizome*); in Solomon's Seal, etc., the apex of the rhizome turns upwards to form the new plant and the rhizomic growth is continued by a lateral bud (*sympodial rhizome*). Marram Grass and Sand Sedge are planted on sand-dunes as "sand-binders." Their tangled masses of roots and rhizomes hold the sand together till the whole is made more compact by the formation of humus from their decay.

With these underground rhizomic travellers which plant out new colonies may be compared long prostrate branches which keep on, or just above, the surface of the ground and carry on the same work of vegetative propagation. Specimens of them are Creeping Buttercup, Strawberry, Creeping Cinquefoil, Ground Ivy, Periwinkle. Their branches are called *runners*. At some of the branch nodes, roots and clusters of leaves form a young plant which becomes independent when the thin connection with the parent is broken. In some plants, such as Saxifrages and Houseleeks, the branches are short and root mainly at the end: the name of *offset* is sometimes reserved for them. These are rosette plants, and the development at the end of the offset will be a little rosette which in some cases does not fix itself by roots until the stem breaks, when it may roll a considerable distance before settling.

The Leaves and their History

Coltsfoot gives us a beautiful model of the folding and the protection of leaves within a bud. Study it in a cluster of young leaves. Pull apart the bases of the two leaves which expanded last and look into the little chamber; within it lies a pointed roll of young leaves. Each leaf is rolled backwards on both sides from the midrib, so that the upper surface is the one left outside; an important detail is that the edge of the leaf undergoes a slight preliminary roll. The back lobes of the leaf due to expand next fit down on the petiole, and in the niche thus formed lies the leaf next in order—all adjusted with such nicety that it looks like a single organ.

Over every leaf stretches a web of silky white hairs, threaded through with faint lines of purple; the web is attached only at the edges, the surface beneath quite glabrous. On unrolling the leaf we discover that the tips of the marginal serrations are never obscured by hairs. They are extraordinarily prominent at this stage; naked, shining, and full of moisture, they lie free in the long narrow spaces within the inrolled margins.

As the leaf unfolds, the web disappears from the upper surface; on the under surface it persists, growing thick and felt-like. It is supposed to prevent moisture from clinging to the under surface of the leaf. The full-grown leaf is large and strong. It is lobed, each lobe being served by a main vein which projects underneath, and is part of a system of bracing ribs which enables the leaf to resist wind pressure. Some branches of the veins terminate in the apices of the marginal lobes; we have seen the swollen character of these in the leaf within the bud. For some weeks in the life of the wide-spread leaf they remain soft and succulent; then they dry up. Their appearance suggests that they are *hydathodes*, or specialised areas, from which water is excreted in liquid form (Fig. 56). Compare them with the water-excreting leaf-tips in young Wheat (p. 118). Cover young Coltsfoot plants for a night with bell-jars; drops of water appear on all the lobe-tips. Observation kept on a large number of plants for several weeks showed the frequency of the occurrence of the drops; they were most abundant on a dull, still morning—

when evaporation would be slow, following a very warm day and night—when root absorption would be copious. They were more numerous on the younger leaves, and on leaves overshadowed by others; they were formed quite independently of dew. The swollen leaf-tips bear stomata, and are in intimate relation with the ends of one or more fine veins. They would be of special service to the web-enfolded leaf within the bud; through them respiration and transpiration could go on into the space in which they lie free, especially as the apex of the leaf-roll opens early and air circulates within that space.

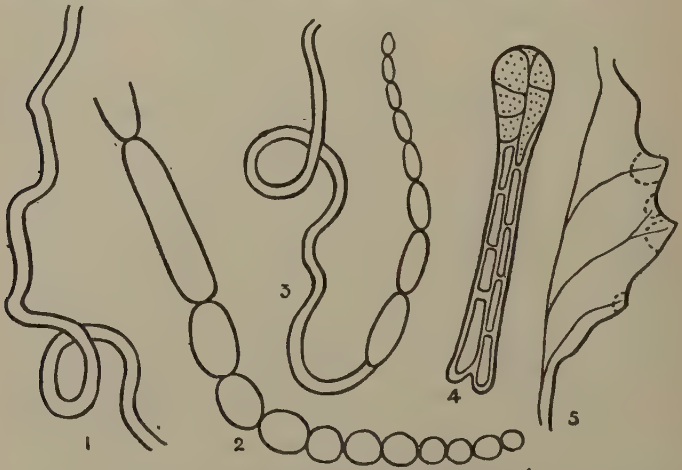


FIG. 56. COLTSFOOT: HAIRS AND HYDATHODES

(1) Part of white hair from leaf; (2) "Bead" hair, coloured; (3) This shows connection between (1) and (2); (4) Coloured "knob" hair, dotted part is red; (5) Leaf-tips showing areas on which calcium carbonate from hydathodes had collected.

Some of the many modifications of plant *hairs* are illustrated in Coltsfoot (Fig. 56): (*a*) Much of the purple colour which is characteristic of it is located in hairs of *glandular* type; they are scattered over the inflorescence, the scale-leaves, the stem, etc. They are of epidermal origin. A reddish-purple head, club-shaped, surmounts a colourless or greenish stalk. The stalk is multicellular; the head consists of several cells filled with reddish substance. The hairs of the web are of two kinds, one of which is a modification of the other. (*b*) The grey colour is due to excessively long cells, much crinkled and twisted; they seem to be unicellular and to be empty. (*c*) The prolongations of the crinkled cells give the purple flecks which break through the silvery web. They are graduated chains of purple " beads," which under the microscope are seen to be the partitioned extremities of the colourless hairs. Even when the plumule of the seedling is less than a millimetre in size, these *bead-hairs* are recognisable; they are then filamentous in part and colourless. This string of coloured, richly protoplasmic cells, the termination of a *very* long empty filament, is a strange combination. The seemingly distinct sets of hairs may have a connection; as the web and its bead-hairs become restricted on the unfolding leaf, the knob-headed hairs grow more numerous. In both of them we recognise a coloured distal region of many cells attached to a colourless proximal region.

Hairs always originate in cells of the epidermis; they may be unicellular (e.g. root-hairs) or multicellular (e.g. glandular). The hairs of Coltsfoot are colour glands; the hairs of Sundew and other insectivorous plants (p. 142) secrete digestive fluids, give out sticky substances, absorb nutritive substances. The stinging hairs of the Nettle are rather elaborate; put some under the microscope; the tip is brittle and breaks off if it pierces the skin, when acid juice is pressed out from the swollen base of the hair. Thick felts of hairs of every degree of fineness are characteristic of vegetation in Mediterranean lands and on high mountains, as well as of some plants living in damp habitats. The covering may serve a variety of purposes; it may retain heat; it may save the leaf from the action of drying winds; it may prevent water from clinging closely to the leaf-surface; it may protect chlorophyll from light which is too strong.

An explanation of the red or purple colour which appears and disappears in parts of plants which are usually green is difficult to find. The student should enter in his notes what he observes about its occurrence. He will find the reddish flush very common on young shoots, etc., in spring. It is said that it has been proved experimentally that it shields chlorophyll from intense sunlight, that lowland plants transplanted to high Alps survive only if they can furnish themselves with this purplish colour. There are other theories which have not been so well tested. The red colour is in solution in the cell sap, not in chromoplastids. In Copper Beech, chloroplastids and red sap are present together.

The Coltsfoot Flower

The flower-buds, except for an odd few which arise at nodes on the rhizomes, originate from the basal stem, the food reservoir. Their outer, winter covering consists of the scales which later stand apart on the flower-stalk. These are strongly curved and lined with soft hairs; they overlap at the top, forming a many-layered head. They are winter resting buds, and should be examined in midwinter, the relative advancement of the various whorls of the flower being noted. In February the buds begin to rise a little on their stems; they emerge from the soil stiffly erect; as soon as they are touched by sunlight, tints of purple and green creep over the pale yellow of their days of darkness. The flower-stem grows rapidly; the interesting changes which accompany its growth should be noted. The date of full bloom depends on the locality; it is within March and April, speaking generally.

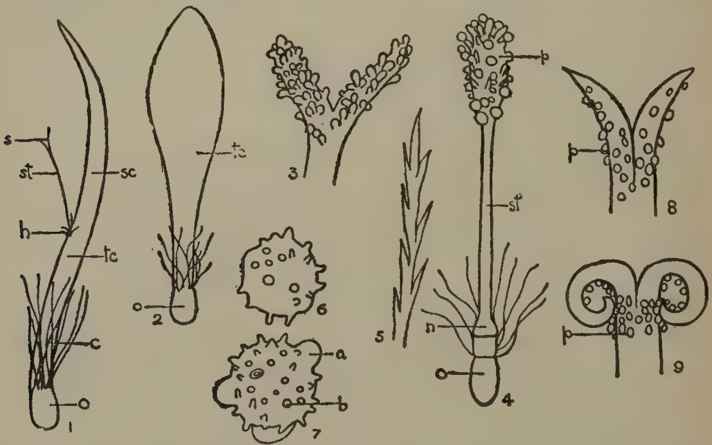


Fig. 57. Coltsfoot: Pollination

(1) Ray floret; (2) Disk floret; (3) Open stigma from ray floret; (4) Pistil from disk floret; (5) Calyx hair from ray floret; (6) Pollen, dry; (7) Pollen, moistened; (8) Dandelion, condition favourable to cross-pollination; (9) Dandelion in condition favourable to self-pollination.

c, calyx pappus; *tc*, corolla tube; *sc*, strap region of corolla; *o*, ovary; *n*, nectary; *st*, style; *s*, stigma; *h*, hairs; *p*, pollen; *a*, protruding inner coat of pollen grain; *b*, warty outgrowth from outer coat of grain.

The Inflorescence is a scape bearing a *capitulum* of closely massed yellow florets. The stalk bears a number of dull-red or reddish-green bracts, long silvery hairs extending from their tips to the axis above. The colour in the epidermis is heightened by that in the numerous red hairs. The individual flowers in a capitulum are held together by an involucre of bracts. These bracts give useful material for microscope study of epidermis, chloroplastids, stomata, glandular hairs, and purple cell sap. They display, too, a variation in form associated with the neat fitting together of the bracts. The bracts are of two shapes. The more full-fashioned consist of a thickened medial strip and two thin wings; the more meagre, of the medial ridge only. Sometimes the "wings" of the adjacent bracts overlap; the narrow bracts cover the "wings" in some cases.

The head of the floral axis is expanded into a flat or convex disk; the florets are fixed on it in pit-like depressions; they are grouped as the *ray* and the *disk*, in the latter arranged spirally, in the former irregularly. There are no scales (bracts) associated with the individual florets as in the capitulum of the Sunflower.

The Ray Florets. The calyx is represented by a ring of spiny hairs, a *pappus* (Fig. 57). The corolla is tubular in the lower part, *ligulate* (strap-shaped) above. There are no stamens; the bifid stigma projects from the slit corolla-tube. The ovary is formed from two carpels, as is shown by the bifid stigma. It is one-celled, and the single ovule is seated on a *basal* placenta. Notice the puzzling little outgrowths, like stubby miniature fingers, which stand just where the corolla-tube splits to form the strap; watch for variations which may help to explain their nature and that of the minute strips near them. The ray florets have no nectaries.

The Disk Florets also have a *pappose* calyx (Fig. 58). The corolla is campanulate, separating at the top into five lobes. The five stamens are epipetalous; the filaments remain free, but the anthers cohere into a tube surrounding the stigma—the *syngenesious* condition. This anther-tube is a most important character. So are the thin triangular flaps or valves which project beyond the top of the pollen-cases, and which at first are pressed together as a roof for the tube. The stigma is covered with blunt projections; it does not function as a stigma; two rudiments of lips are present, but they never open. The ovaries, which are large, rarely contain more than a trace of ovules. The yellow nectaries show through the bottom of the corolla-tube; when the floret is open they should be tested for sugar.

These florets are examples of *unisexual* flowers, as opposed to *hermaphrodite* flowers in each of which both male and female functional organs are present. The ray florets of the Coltsfoot are female or *pistillate*; those of the disk are male or *staminate*. Within the Family to which Coltsfoot belongs there is much variety in the character of the capitulum. Many species resemble Coltsfoot; in Hawkweeds, etc., all the flowers are strap-shaped and hermaphrodite; Burdock and Thistles are amongst those which have tubular florets only; Cornflower has *neuter* (possessing no reproductive organs) florets in the outer rows.

Pollination. To understand this it is necessary to trace the order in which the florets reach maturity, and also the changes in relative position which the several parts of each undergo (Figs. 57, 58).

Stage 1. Begin with a head which has just opened. Examine the disk florets before they open. The top of the stigma reaches the base of the terminal anther-flaps. The pollen is ripe. The stigmas of the ray florets are not yet open.

Stage 2. The flowers of the ray are ready for pollination, but those of the disk are not yet ready to give them pollen. Pollination from another flower-head has the first chance. The ray stigmas are widely open; no one of the disk corollas is open yet.

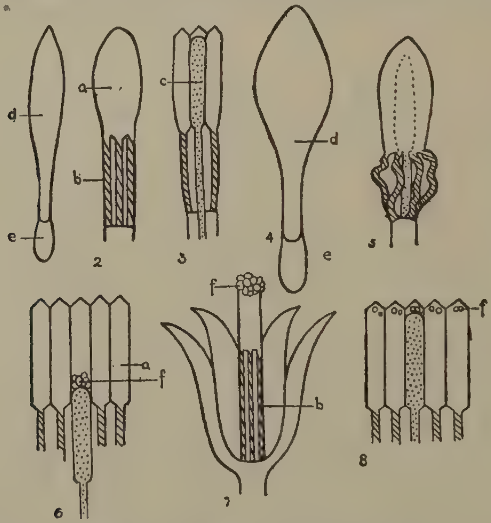


FIG. 58. COLTSFOOT: DISK FLORETS

(1) Young floret with closed corolla; (2) Anther tube from (1), enlarged, filaments straight; (3) No. 2 cut open to show relative positions of stigma and anthers; (4) Closed corolla, more advanced than (1); (5) Anther tube from (4), filaments contorted; (6) Anther tube in stage subsequent to (5); opened to show position of stigma after straightening of filaments; (7) Corolla with straight filaments and elevated stigma, pollen massed on top; (8) Anther tube opened to show stage subsequent to (6), after style has lengthened.

a, syngenesious stamens; *b*, filament; *c*, stigma; *d*, corolla; *e*, ovary; *f*, pollen.

Stage 3. Within this stage self-pollination is possible; that is, in the sense of pollination from florets on the same capitulum, which is rather extending the term. Compare the individuals on a wide-open head at this stage; from the margin inwards you will find: (*a*) a pretty edging of open ray stigmas in a setting of fluffy fringe—the tips of the pappus hairs—pollen sprinkled over all; (*b*) the outer row of disk flowers with open corolla-bells, some anther-tubes closed, some, the taller, open and dusted with pollen;

(*c*) the second row of unopened but bulging corollas; (*d*) the central patch of younger, more slender corollas.

The order of development of the flowers from the outside inwards should be compared with that of the Wallflower—from below, upwards: they are essentially identical.

Stage 4. The receptive period of the ray florets is ended; the styles and stigmas are shrunken. The corollas have grown very long. The disk display is at its height; the central florets lengthen and the surface of the disk becomes dome-shaped; it is heaped with pollen. The nectaries are very distinct. This is the time when the invitation to insects is of the warmest; their mission should be to pollinate from a head at stage 4 one which is at stage 2.

Stage 5. The distribution of pollen has been accomplished. Hitherto, the flower-head has closed and drooped at nightfall. One night it closes and droops as usual, but morning brings no opening and no uprising. The involucral bracts close up firmly and twist a little. The ovary region of the head fills out and hardens. This is the period of seed-ripening; it lasts about a fortnight.

Stage 6. The head rises again, the stalk very much taller now; at the same time the bracts spread apart. Each little circlet of hairs crowning a fruit opens out. For a little, there is poised lightly on its stalk a feathery globular head; then the breezes touch it, and bit by bit it floats away.

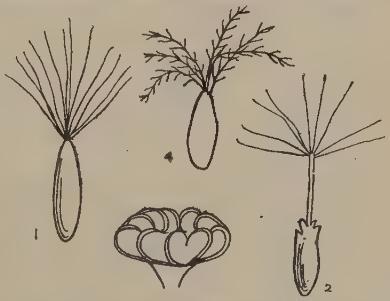


Fig. 59. Fruits in which the Calyx is Modified to Form a Plume

(1) Coltsfoot; (2) Dandelion, calyx elevated on a stalk; (3) Valerian: early stage of fruit, calyx hairs still incurved but lengthening; (4) Valerian, calyx pappus outspread.

The apparatus for *fruit dispersal* is simple and effective. The calyx, that is, the parachute of hairs, makes the small fruit extremely buoyant. It can be readily detached from its pit in the receptacle and may float very long distances. Experiment with some of these fruits. In a dry atmosphere let them drop from a height. If the air is still, they float downwards slowly, swaying gently. Shorten the hairs by degrees and note how the speed of the fall increases. When a fruit falls on damp soil, the pappus folds together almost instantly and lies like a closed umbrella. The spines on the hairs come into action, and so firm is their grip on the soil that a vigorous breath of air may not loosen it (Fig. 57). In this way the seed gets a chance of germinating before the fruit can be moved on again. In Dandelion

(Fig. 59) the pappus is elevated on a long stalk which develops between it and the top of the ovary after fertilisation. The feathery "float" is found in Families other than the Composites. In Valerian, the calyx again acts as a distributing mechanism; during the flowering stage, however, it is only a tight narrow roll; whilst the fruit is ripening, the hairs lengthen, uncurl and form a feathery ring. The white tufts of Cotton Grass, which make a bog look flowery, are long hairs into which the perianths have been altered. These plumed fruits must not be confused with plumed seeds. In these the hairs are outgrowths from the seeds. Get pods of the Willow or Poplar, and watch the seeds (tufted at the base with hairs) as they break out of the bursting pod. Look for Greater Willow Herb when its silvery masses of seeds (tufted at the top) are spilling over amongst the rosy flowers.

The History of a Disk Floret. It executes a clever little performance. First of all, you have the slender, closed corolla-bell, the closed anther-tube, of which the filaments are quite straight, and within this tube the stigma, of which the blunt tip reaches the top of the anther-tube (Fig. 58). Next, the filaments lengthen tremendously, but have to arrange their extra length in coils, the corolla widening to accommodate them. Then two events happen, suddenly and together, so that it is not safe to say which is cause and which effect. The corolla bursts open and the coiled filaments jerk upwards like springs released from tension. By warming a flower you may chance to see the little explosion take place. The sudden elevation of the anther-tube will leave the stigma behind. The pollen is shed, and drops into the space above the stigma. There follows remarkably swift growth of the style, which carries up the load of pollen till it pushes open the three triangular valves. The pollen rests after that as a coherent mass on the top of the tube.

The *pollen* (mounted dry) should be examined microscopically (Fig. 57). It is of the type likely to adhere to insects, etc.; this is due partly to its rough coat and partly to the presence of globules of oil. It is spherical; its surface is made uneven by sharp projections, interspersed amongst which are disk-shaped areas of thin wall. Draw a film of water under the cover-slip of your pollen preparation. The moment the moisture touches the grains, the thin-walled disks shoot out into bladder-like knobs. Water has been absorbed. Apply the test to unopened anthers; the case flies open and the pollen pours out in streams of grains or in rolls. This demonstrates one reason for protecting pollen from rain. Note also, when the water is added, how many very small globules are set moving; they are oil-drops which had been distributed over the surface of the coat. The pollen of Fuchsia is rendered adhesive by a viscid substance with which this oil may be compared in its action. The disk areas of the pollen grain come into operation when the pollen has settled on a functioning stigma. The stimulating fluid secreted by the stigmatic cells diffuses into the pollen grain, which increases in size by a slight outward distension of the thin areas. The inner layer of the wall of the grain may grow out at one of these spots as the pollen-tube—to pass down the style into the ovary (p. 35).

As the flowers are unisexual, *cross-pollination* as between floret and floret must be the rule. But the small flowers are so closely placed that one is tempted to treat the head—in respect of pollination—as one flower, and to talk of cross- and self-pollination with reference to it. It is an excellent type of an insect-pollinated inflorescence—brilliant colour, a convenient platform for alighting and moving about, hidden nectar, adhesive pollen. Nevertheless, the earliness of the season of bloom lessens the likelihood of insect visits. The most numerous insect visitors are *Diptera*, of which about twenty species have been observed; then come Hive Bees and Humble Bees; *Thrips* travels busily all over the heads.

Self-pollination as between the florets on a head is highly probable. The sequence in which the florets open has been outlined; it is, however, carried out within so short a time that the two sexes of flowers may be functioning at the same time. Whilst the flower is open, the wide-lipped, female, ray florets are well separated from the disk florets piled high with their pollen. But as the head closes for the night the stigmas are carried centrewards, and probably come in contact with the pollen. When the head bends over, the pollen masses may tumble down on the stigmatic surfaces. The same will happen on dull, cold days, when insects are few.

There are a great many devices which secure both cross- and self-fertilisation in the members of the Coltsfoot Family. They must be studied from specimens (see Dandelion, p. 176).

Periodic Movements in Coltsfoot

Diurnal Movements. In an open situation Coltsfoot responds to changes in light and heat. In early morning it bends its partially opened cup towards the slanting rays of the sun; widespread, it looks up at the midday radiance; as the sun sinks, its light still penetrates between the closing petals of the flower-head, now curving towards the west. In warm sunny weather, the flower-opening begins before 6 a.m., and is complete by 9 a.m.; between 5 p.m. and 6 p.m. it is closing. Flowers growing in shadow close earlier, and a moist atmosphere induces closure. Even in bright sunshine there will be no opening if the wind is keen.

Many capitula close at night; the Dandelion when closed is covered by the inner of its two whorls of bracts; Salsify is "John-go-to-bed-at-noon," because it closes about midday. Many single flowers also close at night, e.g. Tulip, Wood Anemone. On the other hand, Evening Primrose, Tobacco, etc., open in the evening. The advantage to the plant of night closing and bending is that honey and pollen are protected. An interesting example for contrast is the Garden Nasturtium. It does not close at night, and it does not turn towards the sun. The flowers remain wide open in heavy rain: there is no bending. Water rarely gets into the centre of the flower, and never into the honey-spur. In ordinary rain, the angle at which the flower stands and the overarching of the hood keep out rain very well; drops sliding inwards from the lower petals run out through the spaces between the petal limbs.

The Fruiting Curvature. During the whole period when the fruits are ripening the Coltsfoot head remains inverted. The slight night curvature of the flowering period is increased until the two parts of the stem are parallel. A prolonged set of observations on many specimens made it clear that the average time for ripening is fourteen and a half days, that during that time the flower-stalk gains 9·4 centimetres, that the gradual raising of the head and the opening out of the pappus takes three to four days.

Compare changes in position which occur in some flowers as they develop from bud stage onwards. The Bluebell has been noticed already (p. 48). White Clover is erect in bud, horizontal in flower, pendent during ripening.

The Seedling

The fruit may travel far and in very modern style; it is entertaining to see one swing in at a railway-carriage window and settle down beside you on the cushion! In its chance drifting it may find a better spot than that—moist and open soil where a broad leaf makes a friendly shade. As if grateful and weary, it closes up its sunshade and sinks into restful stillness. But not for long. The little brown akene which lay down had a badly fitting brown coat; a couple of hours later its body has filled out and the wrinkles are gone. The embryo had at once set itself to drink in the water so conveniently near it.

The Coltsfoot fruit contains a single seed. The embryo fills the seed; about half its length is hypocotyl and radicle, and the rest two slightly unequal cotyledons; the plumule is rudimentary. It is a seed which germinates best immediately after ripening; it soon loses vitality. This characteristic, together with the extreme susceptibility of the young seedlings to drought, probably explains why seedling plants are not more common.

If you want to watch the germination of Coltsfoot, drop a few fruits on moist soil and leave them. Only a few of the details of their progress can be referred to here. The first is a temporary absorbing structure. After the radicle emerges, its junction with the rest of the embryo is marked by a thickened ring from which a fringe of long soft hairs spreads round in a circle; they merely touch the soil, but they stick to it; they die away when the normal root-hairs develop. Next, observe that the cotyledons have to do the work of foliage-leaves for two or three weeks, until the first of the latter opens out. Again, the sequence of leaves (p. 24) is: linear cotyledons, a spoon-shaped leaf with an entire margin, a leaf with fine lobe-tips very prominent, a more deeply indented leaf (Fig. 60). Seeing that almost the entire branching system of the adult plant lives underground, the appearance of the first branches from the seedling stem is noteworthy. They rise in the axils of the cotyledons. The third rhizome comes from the axil of the first foliage-leaf. The rhizomes soon strike downward—distinctly disobedient to the geotropic law for branches. A seedling in the open in September is well prepared for the winter; typically, it has seven or eight leaves, a profusion of roots, half a dozen rhizomes, and a stem already enlarged at the base of the leaves. There is no evidence of flower-buds being formed in the first year.

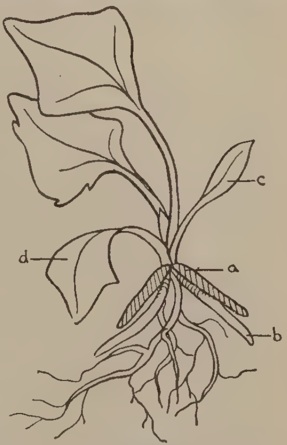


FIG. 60. COLTSFOOT SEEDLING SHOWING FIRST RHIZOMES

a, First pair of rhizomes; *b*, cotyledons in axils of which (*a*) arise; *c*, first foliage leaf; *d*, second foliage leaf.

COMPARISON OF COLTSFOOT WITH BUTTERBUR AND DANDELION

Butterbur (*Petasites vulgaris*) is the nearest relation of Coltsfoot. The greatest difference in their habitats is that Butterbur is much better suited to water-logged soil. Its build is altogether on a bigger scale; the subterranean shoots are massive, branch freely and send up aerial leafy and flowering tips. Flowering takes place in early spring; the rosettes of young leaves often grow a few inches before the opening of the flower-buds, which rest as in nests of down within their expanded bases. Then the inflorescence shoots up rapidly, and has completed its cycle before the leaves grow much more.

The main peduncle bears bracts (or bracteoles) which illustrate well the nature of such structures. The series of them is graduated from those at the base, consisting of sheathing leaf-base, perhaps three inches long, short petiole, and blade three-quarters of an inch across, to strap-shaped scales at the top which are rudimentary leaf-blades.

On the flower-head there is a great advance beyond Coltsfoot towards complete separation of the sexes on different heads. A common ratio is as follows. A *female* capitulum has (*a*) about fifty slender tubular ray florets, with functioning stigmas and ovaries; (*b*) four disk florets, with campanulate corollas and functioning anthers. A *male* capitulum has no ray region, but consists wholly of campanulate florets like those in (*b*) above.

Pollen is wind-dispersed; it is loose and dust-like and is very plentiful. The style may raise its pollen load three millimetres beyond the tube, and the stigmas of the female flowers stand out strikingly with lips wide open to receive it. There is an absence of strong colour, easy landing-places, and nectar. There are, on the other hand, no hindrances to free movement of pollen in the shape of ligulate corollas or spreading leaves.

Dandelion is in many points a decided contrast to Coltsfoot and Butterbur. It has a deep tap-root but no rhizomic system; its rosette of leaves is green all the year; it flowers freely from March to October, and occasionally in winter. Its rosette always lies close to the soil. The formation of new buds would tend to raise it, but this is prevented by the set of contractile roots (p. 54) which draw it down in the autumn. Before the withdrawal occurs the condition of the axis appears to be one of considerable tension. This was shown once when Dandelions were being dug up from tough clay soil. As the sods were cut away in a small trench round a plant, it quite visibly retreated into the hole—the effect weirdly like the movement of an extraordinary worm.

Dandelion, in common with a few other plants, may produce leaf-bearing branches from roots. These "*adventitious shoots*" grow out from the tap-root when the whole stem region has been removed. It is one reason why Dandelion is so difficult to clear out of the ground.

The flowers are not differentiated into ray and disk; the florets are all ligulate and hermaphrodite. The pollen distribution resembles that of Coltsfoot; one difference in detail is that after the style has pushed the pollen out of the tube, its two lips roll backwards and expose their inner stigmatic surfaces (Fig. 57). The calyx pappus is separated from the ovary by a short neck which, whilst the head is closed for ripening, becomes a long filament.

SPECIAL TYPES OF POLLINATION

The variations in flowers which are connected with pollination are innumerable; some of them have been noticed in the preceding pages; a short summary will be found in the Appendix; the student must make and record his own observations on specimens he finds. Some peculiar cases are given below.

In Primrose, Cowslip, Purple Loosestrife, and a few other plants, there exists a unique device for bringing about cross-pollination. The condition is known as *heterostyly*. Compare together Primrose flowers taken from different plants (Fig. 61). The flower comprises a gamosepalous calyx, a corolla tubular below and spreading out above as a platform, epipetalous nearly sessile stamens, a rounded stigma, and nectarial tissue at the bottom of the corolla-tube. There are two distinct forms of flower. In A, the stamens stand at the level of the corolla-throat, and the stigma about half-way down the tube. This is the "thrum-eyed" form. In B, it is the stigma which stands in the corolla-throat, and the anthers which occupy the midway position in the tube. This is the "pin-eyed" form. The pollen grains in A are larger than those in B; the stigma in B is more roughly papillate than that in A. Loosestrife has three forms of flowers, having short, medium and long styles. The scheme works in this way, the effective visitors being certain Humble Bees and Bee Flies. The insect visiting A gets a deposit of pollen on the part of its body which reaches the throat-level of the flower. If it next visits type B, this pollen-dusted ring will be again at throat-level, and be in position to pollinate the stigma which stands there. During that visit to B, the part of the proboscis which rubs against the low-level stamens will take up pollen which, in a subsequent visit, may reach the stigma of a thrum-eyed flower. Cross-pollination between the two forms of flower apparently produces the best seed. But mathematical precision must not be expected. Pollen from a thrum-eyed flower can and does fertilise other thrum-eyed flowers, and similarly with the pin-eyed. It is said to give seed inferior to the first type of cross-pollination.

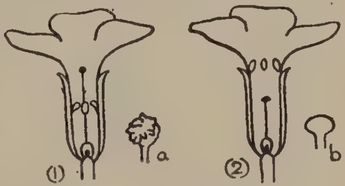


FIG. 61. HETEROSTYLY

(1) Pin-eyed flower of Primrose; (2) Thrum-eyed flower of Primrose. *a*, stigma of (1); *b*, stigma of (2).

Self-pollination is certainly not ruled out in heterostyled plants. In Primrose, pollen may easily be shaken from anther to stigma in the thrum-eyed flower. The Primrose flowers are upright at first, but droop as they grow older, and then pollen may fall on the stigma in the pin-eyed flower. It is also possible that a Bee's proboscis may effect self-pollination as it brushes in and out of the tube. Small crawling insects may be seen travelling about indiscriminately within the corolla. There are, therefore, many chances of self-pollination. The efficacy of the arrangement for cross-pollination depends mainly on the fact that " foreign " pollen is accepted by a plant in preference to its own—is *prepotent.*

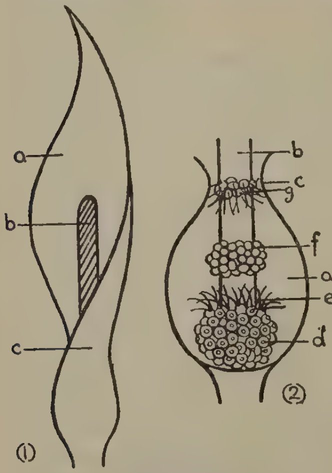


Fig. 62. Pollination of Cuckoo-pint

(1) Cuckoo-pint: inflorescence; (2) Section of (1), further enlarged, showing florets.

a, spathe; *b*, spadix; *c*, constricted part of *a*; *d*, female florets; *e*, ditto, reduced to hairs; *f*, male florets; *g*, reduced male florets with downward pointing hairs.

A very deliberate-looking scheme for securing cross-pollination is seen in the Cuckoo-pint (*Arum maculatum*) (Fig. 62). The plant draws to it numerous Midges by its curious odour and its big green spathe, or bract, in which the inflorescence is enclosed, the dull purple of the apex of the axis contrasting with the green. When the spathe is removed, the trap is laid bare. Round the base of the axis stand the female florets, consisting of one carpel each; above them is a line of sterile flowers, mere hairs; higher than these is a belt of male flowers, having only one to four stamens each; higher still the axis is encircled by rather thick, downward-pointing hairs; the last are placed exactly opposite a very tight construction of the spathe, the lower part of which forms a closed chamber for all the other parts. Although the stamens are placed at a higher level than the stigmas, self-pollination is not possible, because the female flowers are mature before the male. Pollination is effected by small insects which have visited other Arums previously, and which have found no difficulty in slipping down between the yielding hairs of the throat. These hairs make it almost impossible for them to get out, however, for some time. In their wanderings they cover the stigmas with pollen. The next stage sees the dehiscence of the stamens and the withering of the barrier of hairs. The insects escape carrying with them fresh pollen which they may transfer to another set of female florets.

In a few flowers the certainty of self-pollination is provided for, in case cross-pollination fails. Some Violets, Wood Sorrel and one

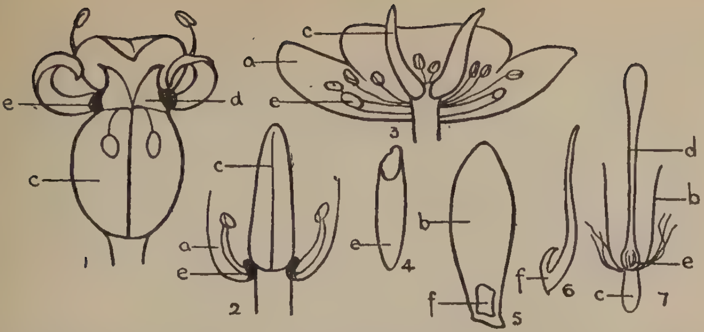


FIG. 63. NECTARIES

(1) Section of Umbellifer: the nectary is a disk formed from the swollen bases of the styles; (2) Wallflower: nectaries lie internal to the base of the stamens; (3) Christmas Rose: nectaries are tubular petals; (4) Tubular petal from (3); (5) Petal of Lesser Celandine, front view; (6) Side view of (5); (7) Coltsfoot: disk floret; nectary lies within the corolla tube at the base of the style.

a, sepal; *b*, petal; *c*, ovary; *d*, style; *e*, nectary; *f*, scale covering *e*.

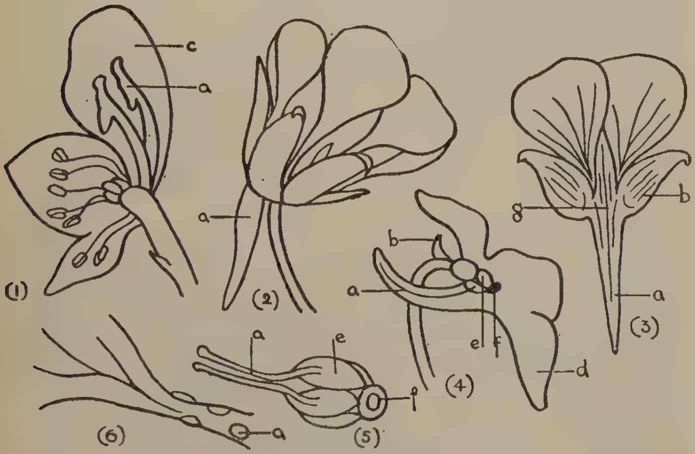


FIG. 64. NECTARIES

(1) Monkshood: two posterior petals are nectaries; (2) Garden Nasturtium: spur is nectary; (3) Garden Nasturtium: sectioned to show "guide" lines to honey; (4) Violet: spur is prolongation of petal; the nectary is an appendage from the anther which grows into the spur; (5) Violet: shows how appendages arise from flattened anthers; (6) Guelder Rose: portion of leaf showing extra-floral nectaries at its base.

a, nectary; *b*, sepal; *c*, posterior sepal; *d*, petal; *e*, anther; *f*, stigma; *g*, "guide" lines.

or two more plants produce *cleistogamic flowers*. At the beginning of the season the normal, brightly coloured flowers are formed. Later, they are replaced by small, greenish, bud-like flowers which keep close to the ground. They never open. Stamens and stigma are in contact. The pollen grains are very few, and never leave the pollen sac; their tubes grow out through the anther wall and through the style to the ovules.

In Figs. 63 and 64 various types of nectary are illustrated.

CLASSIFICATION: FAMILY OF COMPOSITÆ

Coltsfoot belongs to the *Compositæ*, of which the characters are set out below:

Annual or perennial herbs.

Leaves usually alternate, exstipulate.

Inflorescence. Capitulum with involucre of bracts. Tubular florets only, or ligulate florets only, or a disk of tubular and a ray of ligulate florets. Succession of opening, from without inwards. Florets may be hermaphrodite, or male, or female. Scale bracts occasionally subtend florets.

Calyx. Wanting, scaly, or reduced to pappus.

Corolla. Five-partite, gamopetalous, tubular or ligulate.

Stamens. Five, epipetalous, syngenesious.

Carpels. Two, syncarpous. Style single, stigma bifid, ovary one-celled, inferior, one basal ovule. Nectary ring-shaped, round base of style.

Fruit. Akene, often dispersed by persistent plumose calyx.

SUB-FAMILIES

(*a*) **Tubulifloræ.** Some, at least, of the flowers tubular. No latex. Thistles, Burdock, Groundsel, Butterbur, Knapweed are amongst those which have tubular florets only. Aster, Daisy, Yarrow, Ragwort, Coltsfoot, etc., have a tubular disk and a ligulate ray.

(*b*) **Ligulifloræ.** All florets ligulate. Latex present. Examples: Dandelion, Hawkweed, Goatsbeard, Nipplewort.

The Composites form the largest and most widely distributed plant Family in the world; there are over eleven thousand species. Many of our common weeds belong to it. Provision is often made for vegetative reproduction—rhizomes in Coltsfoot, tubers in Artichoke, runners in Daisy. A long tap-root is often present. There is a great variety of insect visitors, because nectar is not too difficult of access. A few special points are illustrated in the following flowers:

The Blue Cornflower (*Centaurea*) has irritable stamens. When the anther-tips are touched, the filaments shorten and draw the anther-tubes down so that pollen is pushed out by the style. Study the actual process and compare with the reversed arrangement in Coltsfoot. Sunflower and Dahlia show the floret bracts well. Burdock has an involucre of hooked bracts; the whole flower-head may be carried round on an animal's coat. Groundsel is an insignificant annual, often self-pollinated. In Bur-marigold it is the bristles of the persistent calyx which cling to animals.

CHAPTER XV

TWO ECOLOGICAL STUDIES

Two ecological studies are suggested by the life-history of the Coltsfoot. One is the place taken by weeds in man's cultivation areas; the other is the story of how a dense community of plants grows up on a bare piece of ground.

WEEDS

The term *weed* is applied to a plant when it is growing in what man considers the wrong place, meaning that it is likely to injure his crops or his stock. So a weed is not always a weed; a Poppy is a weed in the cornfield but not in the garden. Weeds constitute one of the farmer's trials. The following are some of the ways in which they may interfere with his farming. (1) They take from the soil water and mineral food—often the farmer's manures—which should go to the crops, and, by crowding, they deprive them of air and light. In particular, there is danger of slow-growing crop seedlings being smothered by strong weed seedlings. (2) Climbing weeds, like the Bindweeds, may prevent leaves and branches from developing properly, or may pull plants to the ground by their weight. (3) The seeds of the weed may mix with the crop of grain and impair its value. (4) Some weeds (e.g. Cowbane) are poisonous to cattle. (5) Some are parasites or semi-parasites (p. 139).

The cultivator must study the habit of life of the weed if he is to get rid of it effectively. A large number of the weeds on arable land are annuals and produce enormous quantities of seed. They can be kept down only by checking the entry of seeds into the field, and by preventing those plants which get a footing from forming seed. This entails care in selecting pure seed grain, and in clearing weeds from hedgerows; weeds should be destroyed in their early stages. Perennials multiply both by seeds and by vegetative means, e.g. as in the rhizomes and runners of Couch Grass and Silverweed. Wild Tares are climbing weeds. Ragwort, Burdock, Dock, and some Thistles are examples of deep-rooted weeds.

Weeds may be grouped as those of arable land, and those of pasture and meadow land. Both have already been treated to some extent (p. 128).

In cutting down weeds the removal must be made deep down in the root region; otherwise any stem node left will branch again. (Note special case of Dandelion, p. 176). Repeated cutting, through the absence of leaves, starves the roots. Underground stems are the most difficult to get rid of, because every node is a potential plant; spade, fork, plough and harrow may all be requisitioned.

A few notes on individual plants may be added here. Poppies are difficult to clear out, as the seeds may germinate after lying dormant for years; a strong, heavily manured crop may crowd them out. Wild Mustard and similar Cruciferæ sometimes work dreadful mischief. They may be hoed and harrowed to death when young; those which escape should be hand-pulled before they flower. Cleavers is the prickly, straggling plant of the hedgerows; as a preventive, it should be cleared from these. It gets into the crop amongst seed corn, in stable manure, and on coats of animals. Coltsfoot we have noticed. Thistles are universal pests and should be exterminated from every spot possible; their fruits travel long distances. The stem should be cut before they flower. The Field Convolvulus (Bindweed) is very destructive; its rhizomes go very deep down. The only remedy is deep ploughing and repeated harrowing. Clover Dodder and Broomrape are two parasitic enemies of Clover (p. 136). In both cases seed formation must be prevented. The only chance of getting rid of the rhizomes of Couch Grass is to plough and harrow and burn as often as is necessary or possible. The Field Horsetail frequents wet places, and thorough draining may kill it off.

The pasture weeds have to be dug or pulled up, cut close down to the root, treated with special manures, grazed by farm-stock. They include Buttercups, which are eaten by animals only after they are dried; Ragwort, which is eaten by sheep; Yellow Rattle, which may become rampant, and which is of no use as food for animals; Nettles, Thistles, Sheep's Sorrel, Self-heal, Hawkbit, Daisy, etc.

The Development of a Plant Community

On the outskirts of a city notorious for its smoky atmosphere extends a considerable expanse of waste ground; in spring it is yellow with Coltsfoot, in July it is rosy with the Rose-bay Willow-herb; travelling past it by train one cannot tell what else there may be growing alongside these. There are patches of bare ground visible, and the botanist would describe the whole as an *open* plant association. A few years ago the ground was practically bare. It now represents a transition stage in the building up of a plant community, and Coltsfoot and this Willow-herb are pioneers. If it should be left undisturbed by man for a few years, the empty spots would become inhabited, the crowds of plants would grow denser, until it would be impossible for any more to make an entry: the vegetation would then be a *closed* community.

All over the country Nature is having opportunities of setting on foot her colonisation experiments. A landslide exposes naked rock and soil; the crumbling crag face sends fresh loads of fragments over the screes; the river-flood leaves behind it a wide stretch of mud and sand; man piles up spoil-heaps beside his quarries and his mines; new land along the sea estuary may become capable of supporting plants. Some of these the student may be able to follow through their changing aspects. With them may be compared instances of re-colonisation—as, for instance, on a heath which has been burnt or even in a garden which has been left uncultivated. There is interesting comparison which may be made by reading of the peopling of greater areas—of the land completely divested of vegetation by the outbreak of volcanic action; of the perpetual renewal of a glacier's moraine and the perpetual covering of it by Alpine plants; of the great mud-fields left behind by the retreating ice-fields of the sub-arctic land and the peopling of them—a case precisely similar, probably, to what happened over a great part of England when the ice-sheets shrank and left behind the mud which is now our boulder clay.

In studying the colonisation of land by plants, we find that the plant succession varies with the character of the ground, the chief determining factor being the amount of water available. There are many grades; let us take two examples, and add one of re-colonisation.

(*a*) Suppose a landslide exposes new soil and subsoil which are fairly moist. Unless seeds lying there dormant become active, the first-comers will be the best " fliers." You may happen to see some of the fruits drifting down with their parachutes spread, e.g. Composites and Willow Herbs. Little spores of Ferns and Moss may come and succeed in making growth if there is a little shade. Wind-borne spores, seeds and fruits will have better chances if the situation is open. Birds may be carriers. What seeds come will depend greatly on the vegetation in the immediate neighbourhood. The colonisation observations furnish a good opportunity of applying the student's general knowledge of fruits and fruit dispersal, and of testing the efficacy of modifications connected therewith.

To follow the succession of stages of a new community may require years of observation. At first the plants do not occupy the whole ground; the community is *open*. Gradually, individuals become more numerous and species become more numerous; there is usually progressive increase in the size of the plants which become established. Early-comers may disappear, superseded by late-comers better fitted to the conditions. There comes a time when that particular piece of ground, with its particular conditions of soil and climate, can admit no more plants; it is *closed*. After this the personnel of the community does not alter materially; there is a stable adjustment amongst its members; the fittest of the competitors have survived. There may be one species which is more numerous than any other; it is the *dominant*; or there may be several *co-dominants*. Such a stable community may be described as the *climax* for the combination of factors which marks that environment. On a grand, world-wide scale, where climate and soil are perfectly favourable, the climax vegetation is *forest*, the grand climax being the tropical rain forest.

(*b*) The sequence on a bare, exposed rock surface is far different from that just outlined. Here, there is no soil to start with; it has to be built up by slow degrees. Probably the Lichens (p. 299) are at the very beginning of things on a rock face. They can subsist on the minimum of food and water, and therefore they have some chance of success. In their lives they take a little from the rock and a little from the air, and with these, plus water, they make a little protoplasm. Then they die and the protoplasm becomes humus. The humus mixes with a little mineral from the rock and *there* you have a morsel of soil: it is the genesis of a soil. This goes on. The Lichens are joined by microscopic Algæ, and Bacteria are early on the scene; there is no lack of infecting spores on every wind. The next settlers are Mosses, which make the smallest demands on soils. After this, soil accumulates more quickly, for the Mosses are more active. The first Flowering Plants to get established will probably be small annuals which do not need much soil. After generations of their short lives and early deaths have increased the humus stock, herbaceous perennials move in; then come woody plants—possibly, at the last, trees. The stages of just such a succession may be identified by going from place to place over the bare limestone plateaus (" clints ") of the Pennines, where, in rare instances, the wood has completed the series.

(*c*) A burnt moor is an example of a habitat which is only partially free to start with. The aerial part of the vegetation is gone, but within the soil there may be many seeds which have been waiting a long time for their chance, and there are also the root and rhizome structures of the previous inhabitants. Both of these assert themselves very quickly and mingle with the growth of immigrants. For a time some of the latter may flourish, but the likelihood is that eventually the original moorland vegetation will re-establish itself with little difference. It is of interest to note the quality of the young growth—for example, the rejuvenation of heath plants. Birds play a great part in distributing the " berry " moorland fruits.

Students who have frequent access to sea-coasts should use their opportunities well. These are places of perpetual change; land is being made, land is being stabilised and colonised, land is being eaten away. There is an interesting succession on the sand-dune and the shingle beach, depending largely on the formation of humus and the binding properties of such plants as Marram Grass, Sea Purslane, Sand Sedge, Sea Couch Grass, etc. The changing vegetation features of salt-marshes in northern France, of shingle banks, etc., in south-east England and of mud-flats along estuaries in west Wales have been under skilled botanical observation for years.

CHAPTER XVI

INTERNAL STRUCTURE OF PLANTS

In Chapter VIII the cell, as being the unit from which the plant tissues are built up, was examined. There, *Spirogyra* was seen to be a many-celled plant in which all the cells appeared to be similar and to have similar work to do. In higher plants, cells have become specialists, adapted to special functions. In order to follow with understanding the processes which make up a plant's existence, we must know something of these cells. We will take in turn the tissues of root, stem and leaves. The microscope will be necessary, but before using it, much may be learnt from the specimens by naked-eye and simple-lens examination. (It will be understood that it is beyond the scope of this book to give detailed instruction in section-cutting and mounting.)

Root Structure

Sections may be dealt with in something like the following order: (1) Transverse sections through very young roots; (2) longitudinal sections through the same; (3) transverse sections through older roots; (4) sections through the apical region of the root; (5) longitudinal sections showing origin of roots from roots.

(1) For the *root* we may use the Broad Bean. A transverse section through the root-hair region will show young tissues (Fig. 65). Such a section shows the cut ends of structures; it must be carefully correlated with longitudinal sections, which show their other dimensions. A root is plainly divided into a central cylindrical portion and a surrounding envelope. The latter has clear boundaries. The cells in the external layer—the *epiblem*—are regular in shape, fit together exactly, and have slightly thickened outer walls. Some of them are prolonged outwards by thin soft walls; these are the root-hairs (*r*), hence the layer bears the other name of the *piliferous layer*. The inner boundary wall is the *endodermis* (*en*). It consists of a single row of cells which are close-fitting. Where they touch each other the wall is much thickened; this thickening (the Casparian strip) is a band which wraps right round four sides of the brick-like cell, leaving free two opposite sides as passages from the exterior to the interior of the root. In the section it shows in the

dark radial walls. The endodermis is usually packed with starch, even when other tissues are free. It belongs to the cortical area.

Between epiblem and endodermis (inclusive of the latter) lies a wide belt of more loosely arranged cells—the *cortex*. They are rounded or irregularly angular, have thin walls and protoplasmic contents. Numerous intercommunicating spaces are left amongst them—the *intercellular spaces*.

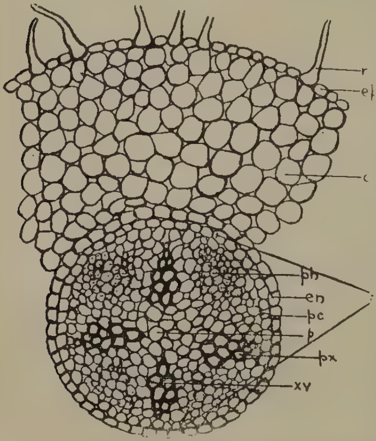


FIG. 65. ROOT OF BROAD BEAN: TRANSVERSE SECTION

ep, epiblem; *r*, root-hair; *c*, cortex; *s*, stele; *en*, endodermis; *pc*, pericycle; *ph*, phloem; *xy*, xylem; *px*, protoxylem; *p*, pith.

Everything situated within the endodermis constitutes the *stele* or *vascular cylinder*. Prominent in the stele are four groups of elements placed crosswise; they are the *xylem* or *wood* tissue; the number is not the same in all roots. A xylem group stands out very clearly by reason of a small number of its elements; their walls are angular and heavily thickened; they stain yellow with aniline chloride; they contain no protoplasm. The very largest of them lie nearest the centre; those nearest the endodermis are very small. The latter were the first to be formed and are known as the *protoxylem*. As the wood increases in extent, additions are made towards the centre of the stele.

Alternate with the xylem "bundles" (i.e. strands), lying on alternate radii, are four groups of much more delicate cells. They are smaller, have thinner walls of cellulose, and their contents are abundant; there are no spaces amongst them. These are *phloem* or *bast* bundles. The relative positions of xylem and phloem tracts must be carefully noted.

A regular and very important layer of cells forms an unbroken sheet just interior to the endodermis; it is the *pericycle*.

The rest of the stelar tissue, filling the centre and the spaces between xylem and phloem strands, consists of ground tissue or *pith*, the cells of which are large and thin-walled with spaces between them. The bands of ground tissue which run out between the bundles are known as *medullary rays*.

With this root of Broad Bean may be compared a very young root of Wallflower. In this there is no central pith; there are two xylem strands which, at a very early stage, increase till they meet in the centre and form a solid plate of wood (Fig. 66 (1)). In the root of the Creeping Buttercup there are four xylem bundles which unite in the centre. The root of a Monocotyledon should be compared with these Dicotyledonous roots; the number of vascular strands is larger.

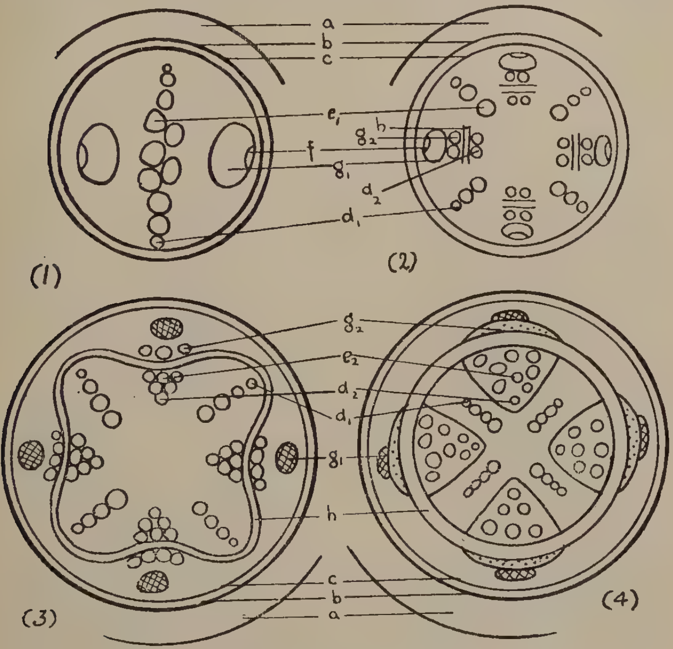


FIG. 66. SECONDARY THICKENING IN ROOT OF DICOTYLEDON (DIAGRAMMATIC)

(1) Root with two xylem strands, no secondary tissue; (2) Root with four xylem strands; cambium opposite phloem strands; (3) Wavy cambium ring; (4) Circular cambium (on smaller scale).

a, cortex; *b*, endodermis; *c*, pericycle; d^1 and d^2, protoxylem (1) and (2); *e*,^{1} and e^2, xylem (1) and (2); *f*, protophloem; g^1 and g^2, phloem (1) and (2); *h*, cambium.

The above is a very bald and far from complete set of statements. Longitudinal sections will make it clearer, and some meaning will be put into it when we consider its functions (p. 268).

(2) Cut a longitudinal section about the same level as in (1); get one which passes through two xylem strands—it will, of course,

miss the phloem strands, to see which another section must be made. The most striking character is the great length of many of the elements as compared with their width. The cells of the epiblem are the least lengthened; they would show as being approximately equal-sided on the surface of the root. Those of the cortex and the pith are rather more elongated; those of the endodermis and pericycle are short in longitudinal section. The chief elements in the wood and the bast are excessively long. They are similar to those found in stems, and their details will be more easily seen in stems, where they are larger.

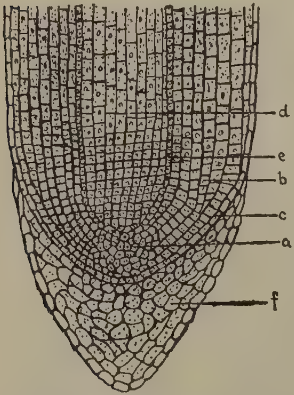


FIG. 67. GROWING POINT OF ROOT

a, mass of actively dividing cells from which all layers originate; *b*, layers giving rise to cortex; *c*, layer continued as epiblem; *d*, cylinder which gives rise to new stelar tissue; *e*, endodermis; *f*, root-cap, perpetually renewed from *c*.

Putting together what is learnt from the transverse and the longitudinal sections, we see that the cylindrical root contains a series of cylinders fitted one within the other—cortex, endodermis, etc. The circles in the transverse sections are the cut edges of these cylinders.

(3) To provide for the thickening of a root or a stem, new wood and bast are added on as the result of the growth and repeated division of well-defined layers of cells within the stele (Fig. 66). These cells are spoken of as being *meristematic*, and they constitute the *cambium*. The procedure is not too easy to follow in the root, and it is not the same in all roots. In some instances there can be traced a meristematic layer which follows the inner edge of the bast area and arises from modified pith cells; this is continued round the outer edge of the wood area, involving the pericycle cells. There thus comes into existence an encircling belt of actively dividing tissue which is at first a wavy line, but which straightens with growth into a circular band. The cells in the cambium divide and develop in such a way that those cut off on the outside of the band become new bast, and those on the inside, new wood. Hence, in this secondary vascular tissue the oldest elements of xylem are nearest the centre, and the oldest phloem nearest the circumference. Internal to all the new tissues lies the little area of primary xylem bundles.

There is no secondary thickening in the roots of the Monocotyledons.

Another change takes place as the root grows older. The pericycle doubles its cell layer. From part of the inner layer new vascular tissue is derived, as has been seen. The outer layer enters on a division phase also; this latter cambium is given the special name of *phellogen*, and is the origin of cork tissue (Fig. 76). As soon as the cork layer is complete, all the tissues external to it dry up and fall away. The phellogen furnishes then a corky bark, as is seen in older roots.

(4) Make a longitudinal section which includes the root-cap and the length of root adjacent; this will show how the root increases in length (Fig. 67). The compact cellular region immediately above the root-cap is the *growing-point*. The cells are cubical or polygonal in shape and are filled with dense protoplasm. They all take part in the formation of the new tissues. By the division of such of them as lie in axial line with the cortex, new cortical tissue is added; from those in line with the vascular cylinder are obtained additions to that. The piliferous layer is extended in the same way. The new elements stretch in long lines upwards, gradually growing better differentiated. From the lowest layers of the meristem, new cells are cut off to join rows in the root-cap, which is constantly being worn away at its extremity.

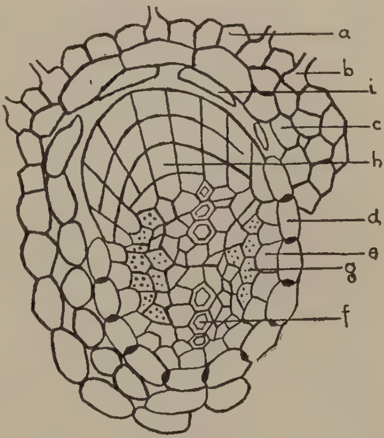


FIG. 68. ORIGIN OF LATERAL ROOT (AFTER VAN TIEGHEM)

a, piliferous layer; *b*, hair; *c*, cortex; *d*, endodermis; *e*, pericycle; *f*, xylem; *g*, phloem; *h*, tissues of new root; *i*, cortex breaking down.

(5) Every secondary root takes origin from tissue within an older root which becomes meristematic (Fig. 68). That tissue invariably is the cells of the pericycle which lie opposite a xylem bundle. By their division, first a plate, and then a many-layered mound of thin-walled tissue is formed. This extends outwards; it does more than push a way through the endodermis and cortical tissues—it " eats " a way out, for the ferments secreted by its cells break down and make fit for absorption the cells which lie in its path. In some cases (e.g. in Wallflower), two rootlets arise at each xylem point, each a little to one side of it. The root has an *endogenous* origin, that is, within the vascular cylinder.

Stem Structure

(*a*) **Herbaceous Dicotyledons.** A beginning should be made with very young stems, including those of seedlings; then older stems should be compared with these. Several plants should be examined, e.g. Dead Nettle, Broad Bean, Wallflower, Sunflower, Creeping Buttercup (the runner) and Vegetable Marrow. Find out as much as possible about the structures before using the microscope for them. Very often leaves, herbaceous stems and roots are reduced to skeletons as they lie about on rubbish-heaps, owing to the quick decay of the soft parts. These skeletons are the woody vascular bundles which we saw in root sections. Search for such. Parts of Broad Bean can be skeletonised by soaking them for a day or two in dilute potash and repeating the treatment with dilute nitric acid; the soft tissues can then be brushed away. From such preparations it can be learnt (*a*) that the vascular tissues of the root are continuous with those of the stem; (*b*) that the vascular bundles from leaves run down the stem through several internodes, and at a certain node join those of the leaves vertically below them. Branch bundles connect up all of them at the nodes. There is continuity in the vascular tissue from root-tip to leaf-tip. The course taken by the strands may be traced by slicing plants longitudinally and applying aniline chloride solution to the cut surfaces. The woody cell walls of the strands at once turn yellow (cf. Fig. 69).

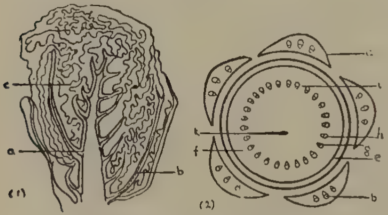


Fig. 69. Brussels Sprout: Course of Vascular Strands

(1) Longitudinal diagram; (2) Transverse diagram.

a, veins of stem; *b*, veins of leaves; *c*, crumpled leaves; *d*, leaf-bases; *e*, epidermis; *f*, cortex; *g*, xylem; *h*, phloem; *i*, medullary ray; *k*, pith.

The Sunflower stem may be taken as the first specimen. A transverse section shows a scheme very different from that in a root. Stain with aniline chloride; a ring of little yellow areas appears at a short distance from the surface; these are vascular bundles (Fig. 70).

The outer layer of cells forms the *epidermis*; these cells contain protoplasm and a nucleus, but no chlorophyll. Hairs are outgrowths from the epidermis; in some plants they consist of one epidermal cell, in others (e.g. Sunflower) this divides to form a multicellular hair. The outer walls of the epidermal cells are thicker than the others, and their cellulose is replaced by cutin which does not allow passage to water or water vapour. These external walls may unite as a distinct outer coat, the *cuticle*, which can be stripped off. Here and there are openings in the epidermis; they are *stomata*, which will be described with the leaf tissues.

The *cortex* differs from that of the root in that it contains chlorophyll. The cells of the outer layers are narrower and longer than in the inner; their walls are still of cellulose, but they are thick and strong; they have living contents. These layers constitute one type of strengthening tissue, and their disposition varies in different stems. They form the tissue *collenchyma*. In the stem of Dead Nettle they are massed at the angles of the square stem. Cortical ground tissue may be changed into another form of supporting tissue, *sclerenchyma*. In this the cells are woody and are dead; they may form a tube round the stem. The air spaces running throughout ground tissue — cortical or pith— generally contain air or water vapour, never liquid water.

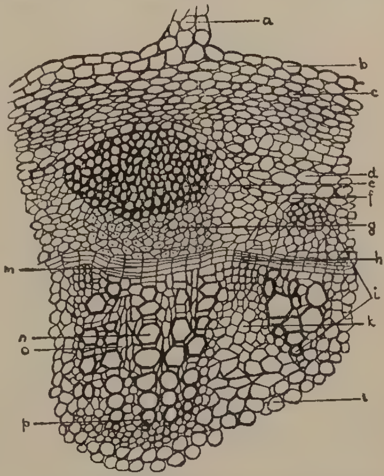


Fig. 70. Stem of Sunflower: Transverse Section of Part

a, base of multicellular hair; *b*, epidermis; *c*, compact cortex; *d*, loose-celled cortex; *e*, sclerenchymatous strand of pericycle; *f*, endodermis; *g*, phloem; *h*, cambium developed between two bundles; *i*, secondary vascular bundle; *k*, medullary ray; *l*, pith; *m*, cambium of main bundle; *n*, vessel of xylem; *o*, fibre of xylem; *p*, protoxylem.

The *endodermis* is not so distinct as in the root, but is essentially similar; starch is constantly present.

Within the *stele* of the Sunflower the vascular tissues are arranged in a circle as compact little masses. The great change from the root arrangement is that *xylem and phloem lie on one radius*, and form one bundle. The phloem is nearest the outside, which is the general rule; in Marrow and Cucumber there is also some phloem on the inner side of the wood. Ground tissue (i.e. unspecialised parenchymatous cells) occupies the centre of the stele and extends as *medullary rays* between the bundles. In the Dead Nettle, the pith breaks down and leaves a central cavity; the vascular bundles are arranged so that large bundles come at the corners of the square stem and smaller ones in between.

The phloem of the stem is continuous with that of the root; the xylem of the stem is continuous with that of the root. In the root, xylem and phloem lie on different radii; in the stem, they lie on the same. The *transition* takes place in the region where stem passes into root. There, a division occurs in a xylem strand of the root, and each of the two parts changes its position, swings round so that its protoxylem faces inwards, and joins a phloem group to form a complete stem bundle. It may be a phloem bundle which divides and sends sections to join two xylem strands. There are other variations.

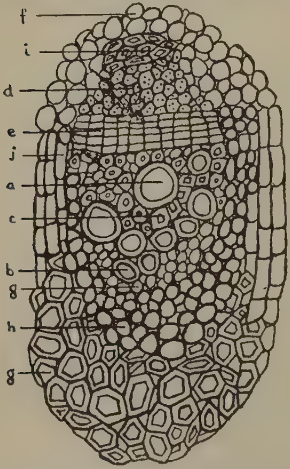


FIG. 71. VASCULAR BUNDLE OF DICOTYLEDON (RHIZOME OF COLTSFOOT)

a, xylem vessel; *b*, protoxylem vessel; *c*, xylem fibre; *d*, phloem; *e*, cambium; *f*, cortex; *g*, unaltered ground tissue; *h*, arc of specialised ground tissue; *i*, strand of sclerenchyma; *j*, medullary ray.

There may be modifications of the *pericycle*. In the Sunflower it becomes many-layered opposite the phloem of each bundle; the cell walls thicken and become lignified; they form a strong strand, well placed as protection for the delicate phloem as well as for general stem support. In Vegetable Marrow this sclerenchyma forms a wavy tube round the stem, outside the bundles.

Examine one of the *vascular bundles* (Fig. 71). The most prominent elements in the xylem are the wide, empty tubes with their rigid, lignified walls. The smallest of them are nearest the centre of the section, which is exactly the opposite of what is found in a root. The phloem elements, thin and soft-walled as in the root, are smallest on the outside of the bundle. Between xylem and phloem lies a tissue which is of the utmost consequence. It consists of several rows of rectangular cells, radiating in very definite rows outwards. They have the appearance of, and they are, cells which are the products of division rapidly repeated, tangentially. This tissue is a *cambium*. The flat plate-like cells cut off from it on the outer side are by degrees changed into the specialised cells of the phloem. Those cut off on the inner side become elements of the xylem. By these additions the vascular bundle grows larger and larger, the direction of increase in the xylem being away from the centre of the stele; in the phloem, towards the centre. There is always much more xylem than phloem formed. At first this *secondary growth* is confined to the bundle. But as the stem grows older, a circular band of the cells in the medullary rays becomes meristematic and gives rise to xylem on the inside and to phloem on the outside of the cambial strip. A stage may be reached when these strips, together with the cambium of the bundles, form a continuous ring of cambium. Bundles capable of enlargement by a cambial layer are called *open* bundles, that is, without limit as to their growth. They are typical of Dicotyledons.

From longitudinal sections the nature of the components of the bundle is made clearer. There are three kinds of element in the xylem—vessels, fibrous cells and parenchyma—and three in the phloem—sieve-tubes, companion cells and parenchyma (Fig. 72).

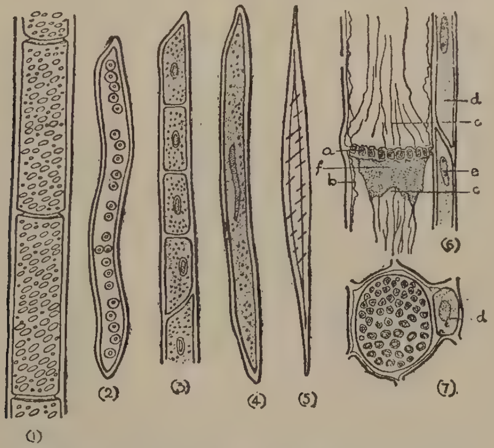


FIG. 72. PRINCIPAL ELEMENTS IN VASCULAR TISSUE
(Copied, with modifications, from Strasburger.)

(1) Vessel; (2) Tracheid; (3) Xylem parenchyma; (4) Fibrous cell; (5) Xylem fibre; (6) Sieve-tube (longitudinal); (7) Sieve-plate (transverse).

a, sieve-plate; *b*, cytoplasm; *c*, nitrogenous substance; *d*, companion cell; *e*, nucleus of *d*; *f*, callus mass closing sieve-pores.

(*a*) A *xylem vessel* is not a single cell. It is a long tube which has been formed by the breaking down of the end walls in a line of long cells arranged end to end. The walls are of woody tissue, the thickening is laid on by degrees in patterns as spirals, rings, etc. Thin places are left in the walls, sometimes so small as to be pit-like; through these water is able to pass. The thick rigid parts of the wall prevent it from being crushed inwards when pressures are very low within the vessels. Those vessels which have spiral thickening are confined to the protoxylem. In their final state the vessels contain no living substance; in the living plant they may contain water and air.

(*b*) The *fibrous cells* are long, spindle-shaped and sharp-pointed. They have uniformly thickened walls of wood, well fitted for supporting tissue. They contain protoplasm and a nucleus; these often disappear as the cells grow older, and the cell is then termed a *fibre*.

(*c*) The *xylem parenchyma* consists of rather long, square-ended cells; their walls are thick and of cellulose; they contain protoplasm, a nucleus and usually much starch.

(*d*) The terms *sieve-tube* and *bast vessel* are often used as equivalents. Strictly speaking the bast vessel can be compared with the xylem vessel. This element of the phloem consists of very long cells placed end to end. The term "sieve-tube" refers to the line of cells, but is also applied by some botanists to the individual cells. The cells can be seen well in Vegetable Marrow, in which they are unusually large. Their end walls are level. They may be compared with the xylem vessels, in which these walls disappear; in the sieve-tubes the cross-walls of the cells are perforated as *sieve-plates*. The walls are of cellulose and are thin. They are sparingly lined with protoplasm, but the nucleus disappears as the cell matures. The cell contents include sugar and nitrogenous matter. In winter the sieve-pores may be blocked by a mass of *callus* tissue.

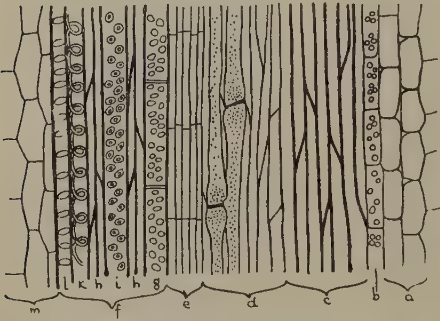


FIG. 73. STEM OF SUNFLOWER: DIAGRAMMATIC LONGITUDINAL SECTION;

a, cortex; *b*, endodermis; *c*, pericycle; *d*, phloem; *e*, cambium; *f*, xylem; *g*, vessel last formed from *e*, pitted thickening; *h*, xylem fibres; *i*, vessel, bordered pits; *k*, vessel, spiral thickening; *l*, vessel, ring thickening; *m*, cortex; *k* and *l*, protoxylem.

(*e*) The *companion cells* are slender cells lying close to the sieve-tubes, from which they have been cut off. They are filled with protoplasm in which lies a large nucleus.

(*f*) The *phloem parenchyma* resembles that in the xylem.

The cells in the *cambium* are narrow rectangles in transverse section, very long rectangles in longitudinal section. They are quite filled with protoplasm (Fig. 73).

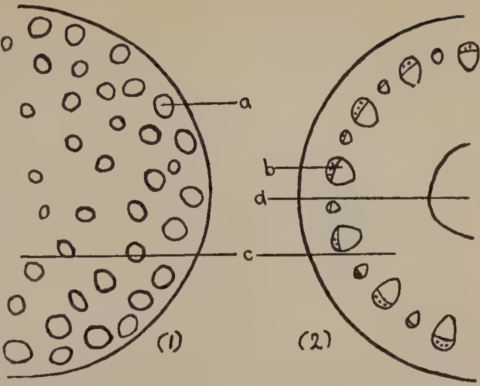


Fig. 74. Arrangement of Vascular Bundles in Stems

(1) Monocotyledon: Maize; (2) Dicotyledon: Acrid Buttercup.

a, closed vascular bundles; *b*, open vascular bundles; *c*, ground tissue; *d*, pith cavity.

(*b*) **Monocotyledons.** Material which may conveniently be used for this work includes Solomon's Seal, Maize, flower-stalk of Hyacinth. The first difference noticed in comparison with the stem of a Dicotyledon is the large number of the vascular bundles and the more general dispersal of them throughout the stem (Fig. 74). The reason for this is to be sought in the course pursued by the bundles which enter the stem from the leaf. They first of all penetrate rather deeply into the central ground tissue, then continue downwards, curving gradually outwards as they do so. The second great difference is found within the bundles. No cambium is present; the bundles are *closed* (Fig. 75). To some extent the stem thickness is increased by the addition of new bundles as leafage increases, or by increase in ground tissue; but the monocotyledonary stem, on the whole, is a cylindrical one.

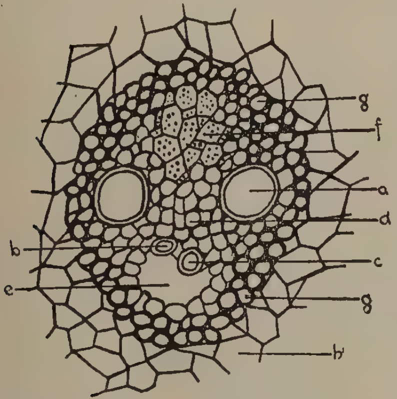


Fig. 75. Vascular Bundle of Monocotyledon: Maize

a, very large xylem vessel with pitted walls; *b*, vessel with spiral thickening; *c*, ring of thickening from vessel of protoxylem; *d*, tracheids; *e*, space left by breaking down of tissue; *f*, phloem; *g*, sheath of sclerenchymatous cells; *h*, thin-walled ground tissue.

Growing Point of Stem. The growing point is at the very apex of the shoot; naturally, there is no root-cap. The great mass of the cells is meristematic as in the root. In the same way certain definite strands of them differentiate to form epidermal, cortical and stelar tissues.

We saw that a new root had its origin *within* the vascular cylinder of an old root (*endogenous*). We find that a new branch has its origin in the cells of the meristematic layers of the shoot apex, from which new cortex is produced, i.e. *outside* the stelar cylinder (*exogenous*). Leaves arise in the same way, a little earlier than the branches. The external layer of the shoot-tip provides the beginning of the epidermis of the new branch or leaf. The cells beneath this divide parallel to the surface, and a small mound of tissue projects as the rudiment of leaf or branch. A whole series of them, the least advanced nearest the apex, may be traced in a young apical bud.

Formation of Bark in Stem. Even in the herbaceous stem the original epidermis does not function throughout the plant's existence; a *bark* is formed. Its origin is often in the pericycle, which does not remain a single layer of cells. The outermost of the additional layers assumes the function of a cambium, becomes, in fact, the *cork-cambium*. It gives rise to living thick-walled cells on the inner side, and to cells which lose their living contents and the walls of which become suberised, on the outer side. Everything outside the cambium is included in the term *bark*, and consists of dead tissues (Fig. 76).

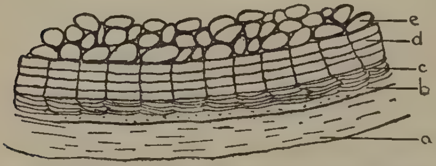


Fig. 76. Cork and Phellogen of Stem of Ribes

a, external layers of bark, splitting off; *b*, zone of splitting; *c*, cork-cells; *d*, cork-cambium from which *c* have been formed; *e*, new layers of cortex arising from *d*, on the inner side.

Leaf Structure

The tissues of the leaf are essentially similar to and continuous with those of the stem. The variations are associated with the special functions of a leaf. As a type should be taken a flat leaf with characteristic upper and lower surfaces (*bifacial*). The vascular tissue is carried throughout a leaf as a network of bundles—the system of veins. Their courses should be studied in various skeletonised leaves, including leaves of Monocotyledons. Many of the finer branches anastomose; the open ends of many lie amongst the soft tissues. The chief vein or veins may project more or less on the lower surface of the leaf, being sheathed in strong hard tissues; they form the main supporting framework of the leaf.

Leaves of Box, Laurel and Privet are favourable for first examination of internal leaf structure; Sunflower gives large veins.

The epidermis is a single layer of flattened cells, close-fitting except for the stomatal openings. The external walls of the cells are very thick and are cutinised; this sheet of external tissue, the cuticle, is most marked on the upper surface of the leaf. The only openings in the epidermis are each surrounded by two cells which differ from the others in their shape and also in containing chlorophyll and often starch; they are called *guard-cells* (Fig. 99). In surface the two cells, when well distended, have the shape of two blunt crescents of which the concave edges face each other; cut transversely they are roughly square. To show stomata plus general epidermis only, the epidermis may be stripped from Broad Bean, Hyacinth or other soft leaf and mounted for the microscope.

The ground tissue of the leaf is generally thin-walled, well filled with protoplasm, and provided with chloroplasts (Fig. 102). In a bifacial leaf, the ground-tissue cells of the upper surface, two or more rows deep, are lengthened perpendicularly to the surface and have only the smallest of spaces between them, if any. Their chloroplasts often take up a position close to the long walls. This is the *palisade parenchyma*. The tissue of the lower part is termed *spongy parenchyma*, from the fact that the cells are separated by many large spaces; they are rounded or irregular in shape. Wherever a stoma occurs it opens into one of these spaces which is particularly large. The cells contain as a rule fewer chloroplasts than the palisade cells, and these more irregularly arranged. The vascular bundles are embedded in the ground tissue, generally abutting on the lower edge of the palisade tissue. Each contains xylem and phloem, but no cambium. The xylem lies uppermost, as it naturally would in continuation of the strands placed interiorly in the stem. As the bundles grow smaller towards their extremities, they grow simpler. The xylem is finally reduced to spirally thickened cells (not vessels), whilst the phloem disappears altogether before the bundle ends. The stiffening tissue which surrounds the larger vascular bundles consists largely of parenchymatous cells with thick walls. It may include sclerenchymatous tissue.

CHAPTER XVII

THE PLANT IN RELATION TO LIGHT

Again and again we have noticed how vegetation is influenced by light. These references may now be gathered together, and may be supplemented.

Light is the visible radiant energy of the sun. What we see as white light is a blend of the colours red, orange, yellow, green, blue, indigo, violet. By directing white light through the prism of a *spectroscope*, we can separate these component colours and spread them out as a band in the order given above; this band is called the *spectrum*. Beyond the visible spectrum extends the invisible; at the end beyond the red can be identified the heat rays, at the other, the ultra-violet, the chemically active rays. The different rays behave in different ways with respect to the plant —an important fact.

As light cannot penetrate far into the tissues, the surface area offered to it must be great—hence the vast leaf area of a tree. Leaves are extremely nicely adjusted that they may obtain that measure of light which they need, and be saved from that excess which would be harmful. This is seen in the many adaptations, such as "mosaics," vertically placed leaves, reduced or extended surfaces, climbers, epiphytes, etc.

In studying the vital processes in a unicellular plant (p. 96), light was found to provide it with energy, and to enable the cell to manufacture sugar—*carbon-assimilation*. We extend the study now to the multicellular plant.

The utilisation of light depends upon the presence of *chlorophyll*. This substance is confined, within the plant, to the specialised bits of protoplasm known as chloroplastids. These in themselves are colourless; they are to be found in all living cells in plants under the name of *leucoplasts*. Within these white bodies chlorophyll may form provided they are exposed to light; a case of this kind is seen when a potato tuber lying partly outside the soil turns green under the light. This does not always happen, for the leucoplasts of the epidermal cells never (except in water plants) become green. Chlorophyll is a mixture of four colours, two greens masking two yellows; they can be separated. Some properties of chlorophyll are easily demonstrated. Take a few fresh leaves; dip them into boiling water; place them in methylated spirit, hastening matters by immersing the dish containing them in warm water. Chlorophyll is not soluble in water, but it is soluble in weak alcohol. Soon the leaves become nearly colourless, and the alcoholic extract green. Hold this extract up to the light; it transmits the green components of light. Divide the liquid between two glass jars. Place one in strong light, the other in shade or in darkness. That in light is soon bleached nearly colourless, the other alters much more slowly. Light destroys chlorophyll; contrast this with the fact that it is responsible for its coming into being. The two processes go on concurrently in the green leaf. In Coltsfoot buds, etc., we see reddish cell sap; this is supposed to protect protoplasm and chlorophyll from injurious strong light. It would do so by keeping back within itself the harmful blue-violet rays, whilst allowing to pass the red rays required for photosynthesis.

Test the chlorophyll by spectroscopic methods. Interpose between the source of light and the prism which is going to analyse it a vessel of chlorophyll extract. The spectrum is much altered; in place of the red-orange band of colour, and of the blue-violet, there are dark bands; these rays have been intercepted within the chlorophyll. The remaining green and yellow rays have been allowed to pass, which is shown in the chlorophyll appearing green to our eye. The rays stopped by the chlorophyll are the part of the radiant energy which is used in the photosynthetic chemical operation. To some extent it has been determined by experiment what each colour does. A plant grown in red light, for instance, forms sugar and starch as well as in full white light; again, the violet rays seem to be those most effective in phototropism.

The green potato illustrates an important function of light: it is only in light that chlorophyll is formed (there is a rare exception in some cotyledons which turn green within the seed). The underground parts of plants, the yellowish leaves you may find beneath loose stones, the blanched leaf-stalks of celery, the shoots and leaves of a potato which has sprouted in the dark, are all examples in which the leucoplasts of the tissues have remained colourless. Seedlings as they emerge from the soil, or when brought from darkness into light in an experiment, soon show green colour.

Upon light depends *carbon-assimilation,* that is, the incorporation of carbon in plant substance. That carbon is got from the carbon dioxide of the air. Keep two pot plants in the dark for a couple of days; then place them on separate sheets of glass and cover with bell-jars, sealing the rims down with vaseline. Under one bell-jar place a quantity of caustic soda, which will absorb any carbon dioxide present. When tested for starch (p. 118), after exposure for a day to strong light, it will be found only in the leaves of the plant unaccompanied by the caustic soda. Carbon dioxide was evidently the source of the carbon in photosynthesis.

Several sugars (e.g. grape sugar and cane sugar) are found in leaves. But starch also is found in the majority of leaves in good sunlight. Both sugar and starch are carbohydrates, and they are easily changed one into the other; which of them is the first to be formed in the leaf? An absolute answer cannot be given, but sugar is the more likely. One argument in favour of this is that in the leaves of many Monocotyledons starch is never found. The formula for grape sugar is $C_6H_{12}O_6$, which indicates the number of atoms present in a molecule. The formula $C_6H_{10}O_5$ for starch does not represent the actual number of atoms, but merely the proportion in which they exist. A molecule of sugar is very simple compared with a molecule of starch. For the latter, we must picture a very large number of groups such as the above formula gives linked together to form one compound molecule; the numbers may be over 200. A formula to express this would be $(C_6H_{10}O_5)x$, where x stands for 200 +. The starch and the sugar agree in that their molecules consist of carbon together with hydrogen and oxygen in the same proportions as in water. It looks possible to convert grape sugar into starch by depriving it of a molecule of water, and vice versa. The equation would be:

$$\underset{\text{Grape Sugar}}{C_6H_{12}O_6} - H_2O = \underset{\text{Starch}}{C_6H_{10}O_5}.$$

The sugar and the starch found in the leaf are the end products of one stage of photosynthesis; quite probably there were other substances formed as preliminaries to them. If sugar is the first formed of the two, it seems to be quickly converted into starch. The leaves may become loaded with it; then by degrees it is reconverted into sugar and passes out of the leaf to other parts of the plant, to serve for respiration, growth or storage.

The presence of starch in leaves is disclosed by the iodine test. In late afternoon take a few leaves from a Nasturtium plant which has been in bright sunshine all day. Boil them for a minute or two; bleach out the green colour in alcohol, wash out the alcohol with cold water. Place the leaves in a dish and pour over them a dilute solution of iodine. They turn very dark blue, nearly black. Compare with these, leaves taken from a similar plant which was kept in darkness during the day. In these leaves there is little or no evidence of starch. Test leaves from plant number one early in the morning of the day following that in which it was first tested. They contain very little starch; it has travelled out of them gradually during the night. Test a leaf which had been detached from this plant and left overnight in water. It still retains its starch because it has broken connection with the organs which took its starch from it.

Let your Nasturtium plant spend another prolonged period in the dark cupboard; test one of its leaves to see if all the starch is gone from it. Arrange now that part of one of its leaves should be kept in darkness. This may be done very simply, without depriving the darkened part of air, by slipping part of the leaf within the sliding cover of a box (a large matchbox suffices). By resting the box on a small plant-pot standing inverted on the soil of the plant's own pot, the leaf will have no strain put on it. Leave the plant in sunshine for half a day. On applying the iodine test, it will be found that starch is absent from that part of the leaf which was enclosed in the box.

When variegated leaves are tested, it is found that starch is confined to the green areas. It seems quite clear that the formation of starch in the leaf is dependent on its being exposed to light, and on its possessing chlorophyll.

Another way of showing that only leaves exposed to light are able to take carbon from the air can be used whether starch is present or not. Leaves selected in ways similar to those above are weighed, and comparison made of the dry weights gained in the course of a day. Again it is found that the plant kept in sunshine gains the carbon.

The carbon dioxide enters the leaf through the stomata. Test this by blocking the stomata in a leaf. Keep a Fuchsia in the dark till all starch is certain to have been removed from its leaves. Select three leaves on it. Smear A on the upper side with vaseline, smear B on the under side, leave C without vaseline. Place the plant for half a day in sunshine, then test. Leaf B shows no starch; the others show about equal amounts. The stomata were closed in B, and that must have cut off the CO_2.

There is continuous diffusion of CO_2 into the leaf cells during photosynthetic activity. The chain of stations consists of the green leaf cells, the intercellular spaces, and the external atmosphere. Possibly equilibrium in respect of CO_2 may exist throughout these during the hours of darkness. But directly light sets going the assimilatory process and uses up some of the CO_2 in the green cell, the balance is upset. Carbon dioxide from the spaces at once diffuses more freely into the cells; this is followed by diffusion of the same gas from the atmosphere into the spaces. This inward stream flows on as long as light is keeping up the manufacture of carbohydrate.

The formation of sugar in the leaf is represented by the equation:

$$6CO_2 + 6H_2O = \underset{\text{Grape Sugar}}{C_6H_{12}O_6} + 6O_2.$$

The oxygen set free can be collected and tested. A water plant (e.g. Canadian Waterweed) is the most suitable. Tie a few shoots to a weight, invert them in a large cylinder of water; suspend over them an inverted funnel and enclose the tube of the funnel in a test-tube. The latter should have been first filled with water and lowered into the cylinder without allowing air to enter it. Place the whole in bright sunlight. Very soon bubbles emerge from the cut ends of the shoots and gather at the top of the test-tube. When the gas thus collected is tested with a glowing splinter it is found to be oxygen. Normally it would escape through stomata; in this case it diffuses through the intercellular spaces and gets out through the cut ends of the shoots. The necessity for CO_2 can be shown by using boiled water in the cylinder and preventing the access of air to it. There is no stream of bubbles; the work has ceased.

The photosynthetic starch is changed into sugar by the enzyme *diastase*, as was the case in seedlings (p. 119). The sugar travels to other parts of the plant as *translocatory* sugar. It may become *storage* sugar within, for example, the cells of the Sugar Beet. It may be carried into the cells of a potato, where, through the agency of the leucoplasts, it is changed into starch. A still further stage may be reached if it is changed into cellulose, a very complex carbohydrate.

Even all these destinations do not account for the whole of the sugar made in the leaf. By a process which is still absolutely secret, the green leaf can accomplish what the man-chemist has so far failed in. It can take nitrogen from a nitrate and cause it to link up with a carbohydrate molecule. This work, too, is done only in light. We know that proteins result from what takes place, and we think it probable that these proteins are preceded by amino-acids, which are simpler; they certainly exist in leaves. They contain nitrogen in addition to the carbohydrate elements. The proteins have extremely complicated molecules; they have, added to the amino-acids, sulphur, potassium, phosphorus, etc. The proteins go to maintain and extend the protoplasm of the cells; protein is also a form of storage material, e.g. in Wheat.

Vitamins. Health research of the present day is concentrating on certain all-powerful but elusive food-substances which have been named vitamins. Their presence in our food is an absolute necessity for our health. Only most minute quantities are necessary, and as they are widely distributed in natural foodstuffs, a reasonably varied diet is likely to give all we need. Five of them have been identified by their action; no one of them has yet shown its actual self to a scientist. They occur in both animal and vegetable food, but can be traced back ultimately to the plant. Outstanding as containing one or other of them are cod-liver oil, lemons, oranges, milk, egg yolk, cabbage, potatoes, green vegetables in general. The great fact that concerns the botanist is that the factories in which the vitamins, or their precursors—*pro-vitamins*, are made are the green parts of plants. How, no one knows. Experiments seem to prove that deficiency in certain of them may be counteracted by the action of sunshine on the animal's skin—which brings us back to the connection of the green plant with light.

The *etiolation* of growing plants deprived of light involves, besides the lack of chlorophyll, structural variations. In Dicotyledons the internodes are extremely long and may become too weak to stand erect; the leaves are very small. The linear leaves of Monocotyledons are exaggerated in length. Evidently light does not encourage stem length. Two plants of equal size and vigour, one kept in darkness and the other in good light, soon show how decidedly light checks growth in length. It is seen also amongst the plants growing on the unshaded high mountains, where rosette forms are common and where stunted branch-growth prevails; almost certainly the strong light in such a situation is one factor causing this. The opposite effect of feeble light is illustrated in the hedgerow climbers. Seedlings of Peas and Beans are very good for experiments in etiolation. One point that has been learnt from recent experiments is that exposure of the plants to daylight for even a few minutes will have a decided effect; for that reason the plants should be examined, when necessary, in red light. In many seedlings, one feature of etiolation is the persistence of the apical curvature known as the "plumular hook" for a long time after the plant leaves the soil.

The *phototropic response* to the stimulus of light is of wide occurrence amongst plants. Window plants, feebly illuminated from the interior of the room, bend towards the light—both stems and leaves sharing in the movement. The growing plant axis which curves over towards a source of light does so in obedience to the law by which light retards growth. The curvature follows from unequal growth of the two sides of the axis. The side nearest the light grows least, and the side farthest from it grows most and becomes convex; hence the curvature (cf. p. 18).

The phenomenon of phototropism in seedlings was introduced on page 74. Experiments may be continued with Millet or Canary Grass as the subject. In some plants, including these, it is possible to find out what part of the plant "receives" the light stimulus. It will be remembered that it was the extreme tip of a root which was the "receptor" for the gravity stimulus. Begin the experiment with a pot of seedlings which are quite erect, the plants in the stage of the rolled leaves. Cover the tips of a few of the young leaves with little caps made of silver paper, excluding light; expose the pot to one-sided illumination. The seedlings with exposed tips bend towards the light; the others remain upright, or bend a little in various directions. The sensitive spot has evidently been protected from the stimulus.

Some *twining plants* execute definite rhythmic movements with their young shoots. Convolvulus, Scarlet Runner Bean and Hop are good examples. The internodes at the top of the shoot are very long and the leaves unusually small (Fig. 77). The part of the apex which has grown beyond a support it is using sweeps slowly round in an irregular spiral; it may take one to three hours to complete its course. This is a case of unequally distributed growth, greater on one side of the axis but moving round the axis; the cause is unknown. As it moves, the tip may touch a fresh support; it winds round this, contact with which stimulates it into a firmer spiral. The movement is known as *nutation* or *circumnutation*. Demonstrate the movement with a pot plant of Scarlet Runner. Give it equal illumination on all sides. Attach to the apex of the stem a light, delicate pointer, projecting a little above the stem. Arrange immediately over the plant a sheet of glass. Looking down on the plant along the line of the pointer make a dot with Indian ink on the glass immediately over it. Repeat the observation and record at regular intervals. Join up the dots; the pointer-tip will thus trace on the glass an account of its movements.

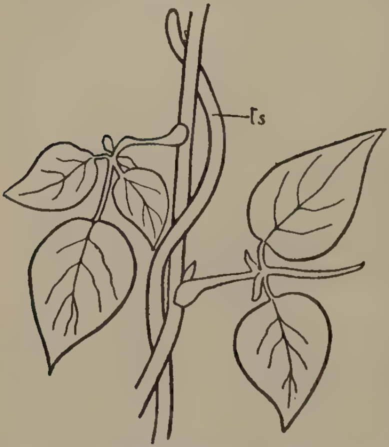


FIG. 77. SCARLET RUNNER: TWINING STEM
Note counter-clockwise direction taken.
ts, long internode of twining stem.

Tendrils are also sensitive to contact, and some of them (e.g. White Bryony) nutate like the twiners. Passion Flower is extremely sensitive. Sweet Pea, Vegetable Marrow, Vetches, behave in a similar way. A young unattached tendril is slightly curved near its end; stroke the concave side of the curve with a rough twig; in a few minutes it begins to coil up. Only after it has touched a support does the slender tendril form its rings; it then becomes stronger and more elastic. The slack length of tendril hanging free between plant and support winds itself into a spiral, reversed in the middle; this acts as an elastic spring, yielding to wind-strains, etc. Virginia Creeper forms tendrils which turn from the light; their tips expand into disks which will adhere to the surface of a wall (Fig. 78).

The *closure of flowers and inflorescences* in response to changes in heat and light has been seen in Coltsfoot, Lesser Celandine, etc. Clover and Wood Sorrel are well known for the "sleep movements" of their leaves. Details of the structures must be worked out from the plants, and day and night positions compared. In the trifoliate leaf of Clover, the two side leaflets place themselves vertical, drooping and face to face; the middle leaflet folds in two along the midrib and places itself as a cap over the pair. The three leaflets of Wood Sorrel simply let themselves drop downwards with their midribs against the petiole. In both cases the mechanism which brings about the movement is a small cushion (pulvinus) of cells situated at the base of the leaflet on the under side. The lowermost of these cells are larger and more thin-walled than the rest. In good light they are tensely turgid, and force the leaflet to remain outspread. The stimulus which gives rise to the leaf movements acts by causing the cell sap to pass out quickly through the thin walls into the intercellular spaces. The cells collapse and, their basal support gone, the leaflets become pendent. A plant in which the same kind of movement is brought about in the same way is the *Sensitive Plant*. A slight shock of almost any kind may act as the stimulus in this case—touching a leaflet, cutting a root, applying heat suddenly, etc. A very interesting series of events ensues. If one of the pinnules (ultimate leaflets) of the bipinnate leaf is the part touched, that droops at once; then the leaflet gives way at the base of its stalk; then the petiole carrying the whole leaf sharply takes a downward direction at the place of attachment to the stem. All these changes follow after the change in turgescence in the specialised cells of the pulvini. The way in which the stimulus

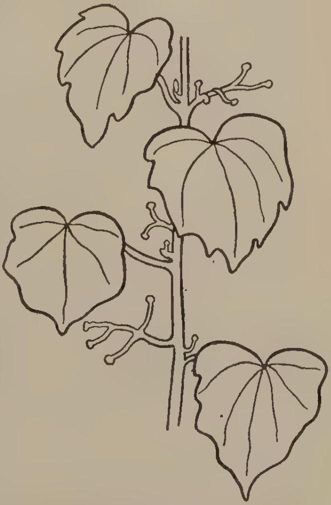


Fig. 78. Branch of Virginia Creeper

Branches modified as tendrils, their tips flattened into adhesive disks.

is conveyed from the place where it was received to the places where in succession it comes into action is still a matter of discussion (p. 302).

The Hedgerow: the Habitat of Climbers

This is a plant home of no great extent but teeming with variety. On the summit of the hedge, bright with sunshine and haunted by birds, are spread gay flowers and fruits; at its feet hide the plainer things which love the shade. The hedgerow plants may wander out into the grass verge and mingle with the company which belongs to that; the ditch which may run alongside will have its marsh plants or its aquatics.

The hedgerow is a man-made habitat, for man started it by establishing in a long row the dominant partner in the business; he continues to modify it by trimming it and by cultivating his fields close up to it. The character of the hedge is determined by the senior partner, the "hedge plant"; it may be the evergreen Holly; it may be the Beech, whose dry brown leaves rattle on its branches throughout the winter and are pushed off in spring; far more commonly it is the Hawthorn, whose mingling of stiff dark twigs and bursting green buds forms one of the most exquisite sights of our spring. Near some of our sea-coasts (e.g. in western Ireland) there are magnificent hedges of Fuchsias.

Here and there the level of the hedge is broken by a tree, the commonest being Oak, Ash, Elm or Maple; see what effect any one of these spreads around it. As shrubs or bushes, may be incorporated Willow, Hazel, Rowan, Crab Apple, Bird Cherry, Blackthorn, Guelder Rose, Barberry and Gorse. Try to find out how the standard "hedge plant" affects the rest of the growth. It is a woody plant; its stem is stoutly upright, its branches are firm; many weaker plants use it to raise themselves to a height. It is a perennial; the ground beneath its canopy is continuously influenced by it. In summer the shade beneath it is deep—deeper than under trees as a rule. At all times of the year, if the dominant is an evergreen, in summer, if it is deciduous, the soil close under the hedge may be very dry. Year after year the leaves drop (for even an evergreen parts with its leaves by degrees) and their remains accumulate as a soil of peculiar, organic quality. The hedge plant with its well-established root system is a strong competitor with any other plants which come near it. The study of the hedgerow should be an investigation into the plant forms and the plant species which are able to adapt themselves to such conditions of light, moisture and soil. In working at this, notice the decrease in the peculiarity of these factors from the bottom of the hedge outwards; remember, also, that it is the seedling's struggle which decides the matter, and its desperate need is for light.

You will remember how the stems of plants growing in poor light shot up with abnormal rapidity. This is fortunate for the young plant trying to live in company with the "hedge plant." It has a chance if it can produce long stems which carry its leaves and flowers and fruits clear of the shade. This rapid growth entails thin, weak shoots, but by various devices such stems make the hedge itself help them up. Most of them are herbaceous and have to start afresh every year; some develop woody tissue and have the advantage of being ready when the season opens. This is the habitat which has many climbing plants to show us.

It is for you to make complete lists of hedgerow vegetation; here, only types will be mentioned.

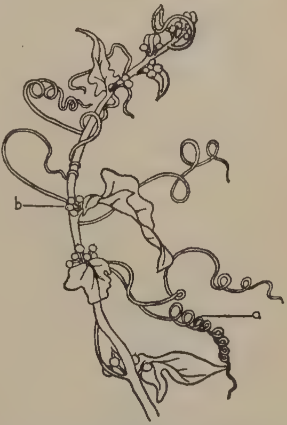


Fig. 79. Tendrils of White Bryony

a, branch modified as tendril; *b*, berries.

The highest levels of the hedge, if they are left to nature, are beautified by the climbing plants which lend to it their gracious curves, their intertwining of foliage and their bright flowers. Their many ways of getting to the top should be studied and sketched. The Rose's prickles are downward-pointing hooks, so they serve as neat grappling-irons by which the weak stem of the Rose lays hold of the stouter "hedge plant"; it is styled a *scrambler*. The Bramble is another scrambler, prickly in almost every part. The Woody Nightshade, or Bittersweet, mounts in a rather irregular way, twining its stems round other stems, either to right or to left, using its petioles in the same way; notice the curious displacement of the leaves and branches on the axes. The Bindweeds (*Convolvulus*) are common; their graceful leaves and sprays and their pure tinted trumpet flowers are very decorative; you will find their stems wound tightly round the supports from right to left. Traveller's Joy (*Clematis*) twines a petiole round a twig and there it stays; its woody stem is more permanent than that of most of the other climbers; it throws out showers of soft pale blossoms. Honeysuckle and Hop have stems which twine from left to right; the former can make use of supports which are thick as a tree, the other twiners can use only thin branches. White Bryony has finely cut leaves, and many tendrils, which are modified branches (Fig. 79).

Other climbers do not reach quite such heights as those mentioned above. Cleavers often does very well with its innumerable little hooked bristles. Vetches climb by their leaf-tendrils; the Hedge Bedstraw is a scrambler.

If Ivy can get a tree or shrub into which to fix its holdfast roots, it may reach the top of the hedge and there spread out in bush form. Under the influence of all-round illumination it branches freely and on all sides of its axis, instead of forming a sheet of branches as when placed against a wall; its leaves then are nearly cordate instead of having the deeply lobed form seen in the wall mosaics. The bushy shoots bear umbels of greenish flowers, succeeded by purple-black berries. Sometimes the Ivy of the hedgerow is content to spread over the ground.

Crowds of plants of shorter habit compete within the strip sheltered by the hedge. Some of them are immigrants from the edges of woods near by, and some from the fields. Make complete lists for the hedges you examine; here are some you may find: Soft Grass, Ferns, Bluebell, Primrose, Wood Violet, Stitchwort, Chervil, Speedwell, Dead Nettle, Foxglove, Stinging Nettle, Lesser Celandine, Nettle-leaved Bellflower, Herb-Robert, Hogweed, Dog's Mercury, Goldilocks, Cuckoo Pint. In the darkest corners you may get Mosses, Moschatel, Toothwort (parasitic on roots of Elm, etc., p. 138); Ground Ivy keeps prostrate on the ground. The divided leaf characteristic of some shade plants is seen in Agrimony, Hedge-parsley, etc.; the linear leaves of crowded communities, in the Grasses and Stitchwort. Whilst very often many species mingle in the lowlier ranks beside the hedge, you may find places where two competitors have managed to eliminate all the others; for example, you may find only Grass and Nettles or only Grass and the Greater Stitchwort.

Trace the sequence of types outwards from the hedge into the field, and across the waste strip to the roadway. Do not overlook the way in which the Bramble spray arches down to the ground and fixes itself there. From any node which comes in contact with moist soil, and more particularly at the tip, adventitious roots grow downwards. Later a bunch of leaves associates itself with the roots; then the parent branch connection is broken and an independent plant is formed. This is another instance of vegetative propagation.

What grows in the ditch by the hedge is determined mainly by the amount of moisture present in it and its permanence. It usually contains much rotting vegetation. Amongst its plants may be rank Grasses, Meadowsweet, Spearworts, Marsh Marigold, Water Cress, Brooklime, Water Crowfoot, etc.

Devise a chart or charts on which you set out and correlate:

(*a*) The variations in illumination in the habitat.

(*b*) The soil variations as far as you can estimate them in a simple way; include moisture condition.

(*c*) The floral aspect.

The fruits of the hedgerow constitute a study in themselves. On the top of the hedge a table of dainties is spread for the birds, enticing to their eye, juicy to their palate; they find there the succulent fruits (not all true berries, but often called by that name) of Hawthorn, Ivy, Elder, Blackberry, Guelder Rose, Honeysuckle, Rose, etc. The birds do the plants a service in carrying off seeds to some distance, behaving in various ways which you should find out. Make lists of the birds which nest in the hedge and which feed on it.

Mixed up with the bird fruits are others, such as Clematis, which have floats of hairs attached to them and which go sailing off on the breezes.

The plants of lower growth, on the other hand, often possess fruits which by their hooked contrivances may be carried around on the coats of animals which brush against them. Such are Burdock, Cleavers, Enchanter's Nightshade, etc.

Make a comparison of the buds of those hedge plants which spend the winter at the greater heights above the ground, with those at lower levels. You will find distinct degrees of protection against drying winds, etc.

Choose, if you have a choice, for your inquiry, a hedgerow which you can visit at intervals throughout the year. Make a calendar in which you enter the succession of plants as they mature. Watch the order of spring arrivals, and especially look out for seedlings. Note the order in which the fruits ripen and note the changing colours of fruit and foliage. Make a collection of fruits typical of the different parts of the habitat.

CHAPTER XVIII

THE LIFE-HISTORY OF THE SYCAMORE

Acer Pseudo-Platanus (Linn.)

The English Sycamore is a convenient basis for the study of tree-form. It is not the true Sycamore, though so called in England; neither is it the true Plane-tree, though that is its name in Scotland. It is really a species of Maple, a foreign representative of the Family *Aceraceæ*, of which the only British species is *Acer campestre*, the Hedge or Field Maple. It was introduced into this country in the fifteenth or sixteenth century; it is now well established and is one of those alien trees which are able to regenerate by self-sown seeds.

This Great Maple or False Plane has several folk-names. In some parts of East Yorkshire it is Seggy; Cats and Keys, Locks and Keys, and Chats are names applied to the fruits. Scottish children make playthings of the partially opened buds; half-open they are " cocks," close-folded they are " hens."

The tree is the climax *form* of plant; its dimensions are the greatest; its massive conducting and strengthening tissues of wood are more elaborate and stable than those of herbaceous plants; it may live to a colossal age. The very greatness of the scale on which it is built introduces to us new problems in water-supply, etc.

Whilst studying the Sycamore, make comparisons all the year round with other trees. Visit individual trees at every season of the year. Photographs of a tree in full leaf, and leafless, disclose marked differences in the droop of the branches. Such a tree as a young Silver Birch is a delightful study in the changing positions of its long, slim branches in the spring days when the buds are growing heavier and the tips are trying to rise. Watch for such changes; watch the opening buds, the dying leaves. Sketch the whole tree in its elegance or its grandeur, sketch the lovely subtle curves of branches, sketch the fair freshness of unfolding leaves.

Tree Form

As I write I notice a clump of trees at a little distance; it suggests a group of buildings; slim spires of Poplars shoot high above domed crowns and irregular masses which plainly are not these Poplars.

We will inquire what laws of growth give to every species of tree a form as distinctive as if it were designed by an architect. We shall find many factors involved, some one of which may confer on the tree its individuality. We shall learn of them through three lines of inquiry. First, the tree must be studied in its seedling and sapling stages, for in the mature tree the branching may be too complicated to follow accurately. Second, a full-grown, well-developed tree must be kept under observation throughout the year. Its form must be analysed, memorised, sketched, photographed; its seasonal changes in shape must be recorded. Third, there should be comparison between trees standing isolated and illuminated on all sides with those growing in woods, or having one-sided lighting. With the Sycamore Maple should be compared as many as possible of the trees referred to on pages 238-47.

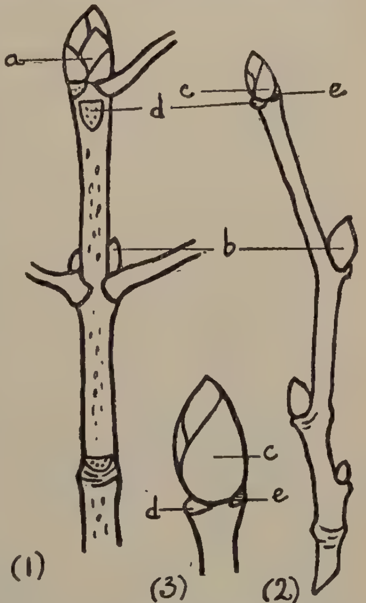


Fig. 80. Modes of Branching

(1) Monopodium of Horse Chestnut; (2) Sympodium of Lime; (3) Detail from (2).

a, terminal bud; *b*, lateral bud; *c*, topmost lateral bud; *d*, scar of leaf base; *e*, arrested terminal bud.

Briefly stated, the main factors are those included in the following paragraphs:

(1) The first lines of symmetry are given to the tree by its original mode of branching as seen in its earliest stages. In the Sycamore, the leaves on the seedling stand in crossed pairs on the stem, and the branches of the first "order" arise in their axils. In Willows, the branches are arranged in a regular spiral on the stem.

(2) A second architectural factor is best seen when the tree is stripped down to its skeleton in winter. Determine then very carefully the angles between the branches of the first order and the trunk, and also the angles subtended by the later orders of branches. In the Sycamore, the first are very wide—indeed, the lowest (i.e. oldest) branches are nearly horizontal; it should be noticed whether or not they are horizontal in the sapling or whether they have assumed that position later. The higher branches of the

Sycamore leave the trunk at steeper angles. Very heavy foliage will tend to drag down the branches of a tree; opposed to this is the normal law directing their growth upwards. In Sycamore, "the summer droop" of boughs is slight compared with that seen in some other trees; prove this by comparing photographs taken in summer and in winter.

(3) The relative thickness of branch and bole (trunk) tells in the shape. The first branches of the Sycamore are sturdy; branches of ancient Oaks may be nearly as massive as the stem; the Ash may divide near the ground into several branches resembling trunks; in Birch the branches remain distinctly subordinate.

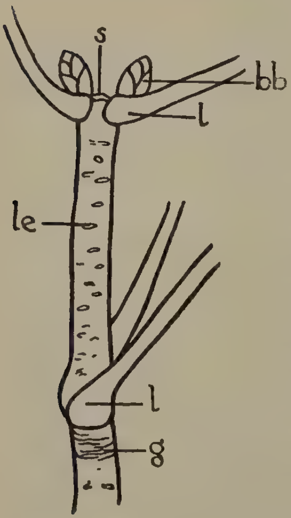


FIG. 81. SYCAMORE: FALSE DICHOTOMY

Shows opposite and decussate arrangement of leaves.

l, leaf-base; *bb*, branch-bud, lateral; *s*, scar of previous year's floral bud; *g*, girdle of scars; *le*, lenticel.

(4) Investigate the various ways in which the main stem (and also the succession of branches) increases in length. Begin with the young sapling. At first, it is the terminal bud which provides new internodes. In the Sycamore, this is the rule throughout the life of the tree, with an exception arising in the flowering shoots. The terminal bud at the apex of the main stem, the *leader*, not only continues to exist, but maintains its supremacy over the lateral buds. So do the apical buds of the branches. The form which results from this tends to be symmetrical, approximately conical. Four ways of building up the axis of a tree can be distinguished. (*a*) The leader keeps the lead, is always more vigorous than the branches; Spruce and Fir are excellent examples. Each axis (of whatever order) is composed of internodes all belonging to the same order of branching; it is a *monopodial axis* (Fig. 80). (*b*) The terminal bud continues its activity, but many lateral buds overtake it in their growth and also grow steeply; a broader, more spreading shape is formed, e.g. Scots Pine, Oak, Beech, Alder. This type of axis is also a monopodium; it is usually impossible to identify the leader in this, the most common form in broad-leaved trees. (*c*) The terminal bud dies. The lateral bud nearest to it is incited to stronger growth, and takes the lead. It often stands so close to the lost

terminal that only a slight alteration in its direction of growth is necessary to make it appear a direct continuation of the growth of the higher order of branch. An axis thus composed of sections belonging to branches of different orders is a *sympodium*. Ultimately, it may be nearly indistinguishable from a monopodium. Examples are found in Lime and Elm. Another case arises when two buds stand at the same level; on the death of the terminal bud both of these form strong axes, and a forked type of branching is the result. This is a *dichasium* or *false dichotomy*, e.g. Lilac. It arises in the Sycamore Maple when the terminal bud forms an inflorescence (Fig. 81). (*d*) Most Monocotyledons which attain tree dimensions do not branch at all, e.g. Palms.

(5) The outline of the foliage masses depends on the arrangement of the twigs. In the Sycamore, they spread at rather abrupt angles, interlacing in all directions. The student should go under the tree and look up, noticing whether or not the crown is hollow. With the Sycamore may be contrasted the graceful, drooping, terminal sprays of Silver Birch, in which the twigs are slender and keep apart; or the Beech, in which the sharp-pointed buds drive straight outwards, their angles of branching small, whilst twigs and leaves arrange themselves as horizontal sheets.

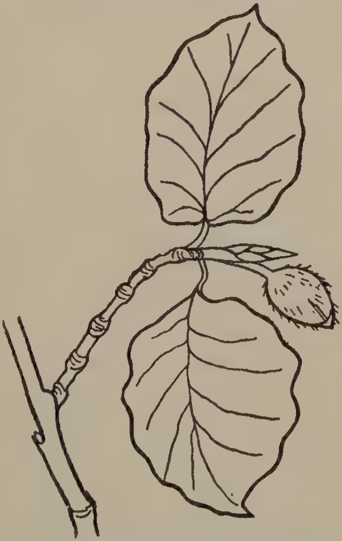


FIG. 82. DWARF SHOOT OF BEECH
Shows six girdles of scars.

(6) In some trees there is a stoppage of growth in certain shoots whilst they are still quite short; at two or three years old they drop off. These short or dwarf shoots are also known as "spurs" (Fig. 82). In the Scots Pine such a shoot carries only a pair of leaves and a few scales (Fig. 92); in Larch, the leafy "tassels" are stumpy little branches shed at the end of a few years; the spurs of the Apple, etc., bear flowers as well as leaves.

(7) Irregularity of form results from the non-development or long-delayed development of buds. Of those initiated only a very few lengthen into shoots. It early becomes impossible for the conducting channels to supply them all with the water and salts

necessary. Those nearest the apex of the shoot are the most favourably placed, and take the biggest share of what is sent up; those lower down get too little and are also handicapped by lack of light. Sometimes the bud is checked so early that its existence is only found out by cutting sections of the wood. Sometimes it appears as a little external bud which shrivels and drops off. The very immature buds may be *dormant* for years, their cells remaining capable of growth and division. If the tree should lose one of its large branches, these buds may start into growth; the streams of food which the lost branch would have got are in part diverted to them. It is in this way that there arise some of the bunches of small branches which look rather misplaced on a stout stem. Some of these shoots, however, and particularly those which cluster round the stump or " stool " after a tree has been cut off within a few feet of the ground, are derived from buds which have *originated* after the mutilation. They are *adventitious buds*, formed out of due order. The great quantities of food which have suddenly become superfluous evidently induce some of the ordinary plant cells to become meristematic (p. 190). Such stool shoots are common in Sycamore. Man often " pollards " trees (i.e. removes their tops) in order to obtain repeated supplies of thin supple branches, e.g. Willows.

(8) Even the twig or small branch has not an assured existence. The laws of plant life provide for a thinning out of these structures. The process is essentially that seen in leaf-fall. It begins by the formation of an absciss layer (p. 225). The twig dries up, may hang on for a while, but is easily detached by wind, etc. After " twig-fall " the ground under Maple and Beech may be thickly strewn with little branches.

A close-planted wood of Spruce or Fir shows branch destruction carried farther, the trees seemingly blasted half-way up their stems. The failure of the branches is due to the depth of the shade under these trees; they break away as dead wood, but not as the result of an absciss layer being formed. Foresters call this " cleaning the bole." It is encouraged, especially in continental forests, by close planting. In such a forest, the very tall, straight, branchless stems—countless down the long vistas—are a very arresting sight to those accustomed to the more open, less uniform woods of England.

(9) The character of the illumination it receives is all-powerful in shaping the tree. Compare the forest tree denuded of its lowest branches with the stately solitary tree of the park, branched and leafy nearly to the ground. The tree at the edge of the wood branches freely on its well-lit side only. It is light, too, which is responsible for the disposal of foliage in approximately horizontal sheets (p. 222).

The dignified Sycamore Maple has grown up under regulation by the principles stated above. Its strong, wide-spreading branches give fine breadth of contour; the successful competition of side branches with leader, is seen in the dome-shaped crown; the angular network of twigs supports the heavy leaf-masses. The massive trunk is in harmony with the height of the tree, the finest specimens of which may be over one hundred feet high.

The Lifetime of a Tree

What may be the span of life in this tree which is the climax form reached in the plant world as man is the climax form in the animal world? What are the phases which make up the cycle of its existence? These are tense questions, for one generation of trees may watch the passing of hundreds of generations of men. The "Big" trees now growing on the Californian hills were probably seedlings and saplings when the Cretan and early Egyptian civilisations were at their zenith.

The oldest tree in the world is said to be a hoary old Cypress in Mexico, with a tale of over six thousand years. Some of the Big Sequoias of California, still healthy and still increasing in diameter, can be proved to be over three thousand years old. In the Natural History Museum in London may be seen a section of one of these "Big" trees, bearing on its rings the principal dates of historical events. These are the long-lived giants of the tree world. Our British trees differ a good deal in the age they reach, and in the relative lengths of the stages through which they pass. The seedling passes into the sapling; the first year of flowering and fruiting arrives; maturity is reached many years after this; and, again after many years, maturity merges into the age of decline. During the sapling phase the predominance of the "leader" usually means regularity in the branching; the open youthful form passes over gradually into the more complex form of the adult tree. It is after the food requirements of the rapidly growing branches have been satisfied that the formation of flowers and fruit becomes possible. Maturity is marked by the cessation of growth in height, but thickness continues to increase; the tree is then at its vigorous, most fruitful best. During the long period of decline, the heart-wood decays, leaves and fruit become more and more scanty, branches break away.

Oak, Lime and Chestnut may reach at least their thousandth birthdays. Our Sycamore Maple begins to flower between thirty and forty; it attains its full height between fifty and sixty; it may live to be two hundred years or so. The Pine may be full grown at ten years of age, and may live to five hundred.

An estimate of the age of a tree can be made with great accuracy after it is felled, by counting the annual rings (p. 231); errors due to breaks in the continuity of the ring-record and to missing rings have to be allowed for. For standing trees, historical records may give help, and calculations may be based on observations made on the rate of growth of the species.

CHAPTER XIX

THE LIFE-HISTORY OF THE SYCAMORE (*continued*)

The Bark of the Tree

The bark of a tree may help to identify it. That covering the bole of the Sycamore is grey; it is free from furrows, except in the oldest parts; it is shed in small irregular flakes. On page 232 the history of bark is spoken of. The layers of cells in the stem which become capable of growth and division (cork-cambium) are of varying extent in different species of tree and occur at different depths in the tissues. In the Sycamore Maple they are shallow saucer-like patches near the surface; it is the bark lying just outside these patches which peels off when interior expansion forces it to do so. On the small branches the bark is smooth, grey or brown, and dotted over with many lenticels. Compare the Sycamore bark with that of the trees on pages 238-45.

The Bud on its Twig

The student must fully appreciate the vital importance of the bud. The seed is the extreme hibernation form involving a whole plant, which carries the living principle through its period of rest or maturation. The resting bud also holds within it the germs, the initials, prepared for a new season's activity. In both cases the hibernating structures must be protected against danger; the dangers include low temperatures, loss of water from heat or drying winds, attacks of animals, rain, fungal growths, etc.

Of such extreme importance did a Danish botanist called Raunkiaer consider this question of bud protection, that he adopted it as the fundamental principle in classifying plant forms. He made use, in particular, of the position relative to the surface of the ground at which buds pass the winter. His views are so full of suggestions that a summary of them is inserted here; previous pages have contained many illustrations of them. His chief classes of buds, associated with definite plant forms (omitting their rather forbidding names), are: (*a*) Buds which spend the winter deeply buried in the soil, e.g. bulbs, corms and rhizome-buds. These do not need stout coverings. They are common amongst desert and alpine plants. (*b*) Buds which rest just within the surface layers of the soil; they are common in temperate regions. We have seen examples in the buds on the tubers of Lesser Celandine. In these also there is no need for elaborate coverings. (*c*) Buds which are situated above the soil, either in contact with it or only a few inches above it. A pasture-field is full of them, e.g. Dandelion, Daisy, Grasses. Some Coltsfoot buds would be placed in class (*b*), some in class (*c*), and the great mortality amongst the latter as compared with the former indicates the greater danger of the exposed situation. Buds need to be fairly well covered if they are to survive here, but the need varies with the climate. In subtropical climates such buds have coats which will prevent loss of water; in semi-arctic, the snow with which they are covered throughout the winter supplements the moderate bud-wrappings. In our own fields the moderate wrapping is sufficient. (*d*) This group includes shrubs and trees, and is subdivided according to the height of the plants. All of them require extremely good protection for their buds. In many cases buds are formed in the early summer of one year, have to encounter that summer's heat, have to be preserved through the extremes of the ensuing winter, and, above all, have to weather the cold, dry spring winds which may touch them when they are juicy with spring sap. The higher the level at which the buds are placed the more forcibly will the winds strike them. Hence we find the tree-bud encased in tough, leathery, or hard, woody scales as in Beech and Ash; scales are sticky with resin in Larch and Horse Chestnut, and in the latter are varnished; sometimes the case of scales is lined with woolly or silken hairs; scales are made to fit tightly and to overlap.

Bud-scales may be derived from any part of a leaf. In Lilac they are very small leaves; in Beech and Oak all trace of the leaf-blade is absent and the stipules form the scales; in Elm and Alder the scales are the stipules of a leaf the blade of which may develop; in Apple both stipule and leaf-base are included in the scale; in Laburnum, Horse Chestnut, Maple and Ash the scales are the bases of foliage-leaves, and it is possible to pick out a series of transitions from a small normal leaf to the extremely reduced scale-base.

Buds have forms so characteristic that they may often be used in identifying trees. Those of Sycamore Maple are egg-shaped and ridged; of Beech, long, sharp-pointed, light brown; of Ash, hard, blackish-brown knobs, etc.

The leaves so carefully swathed and cradled are exceedingly soft and fragile; it is only by degrees after they are opened out that they arrive at the adult appearance. The walls of their epidermal cells thicken greatly and are waterproofed by the development of cutin within them; such walls act as partial screens for chlorophyll, against strong light. One beautiful example is the soft, pale green of the young Beech leaf as compared with the tougher, darker full-grown leaf. The opening of buds is a delightful study; the colours are so tender in their harmonies, the outlines change so subtly. The Beech unfurls its fans and shows for a little their silken fringes; the Horse-Chestnut leaflets point upwards at first, then drop to form a little tent, then spread out as a dark-green umbrella; the Larch needles break out in pale-green tufts from their cases of brown scales.

The History of the Sycamore Bud must be carefully followed. First, make sketches of young shoots in the winter conditions. There will be two forms to compare: (*a*) the monopodial shoot ending in a bud; (*b*) the forked, dichasial shoot, showing in the fork the scar of last season's inflorescence (Figs. 80, 81). Every detail must be noted and recorded. The axis of the shoot will probably be divided up by groups of close-set, narrow scars, each forming a "girdle." Each length will bear crossed pairs of leaf-scars; above each scar, normally, appears a bud. At the apex of the monopodial twig stands a terminal bud, and close below it a pair of axillary buds. In the dichasial shoot the buds corresponding to this pair become terminal buds of new shoots. Numerous lenticels are scattered over the bark.

Second, buds must be dissected, both a foliage-bud and a flower-bud. Make notes of the texture and arrangement of the overlapping scales; remove them and lay them out in series on paper; sketch them. Compare the exposed and the hidden scales. Look for some which show at the tips the arrested leaf-blade, of which the base forms the scale. The removal of the scales leaves scars—the scars which form the "girdles"; clearly, a scar-girdle marks out the position of a terminal bud (Fig. 88). The core of a foliage-bud is a parcel of foliage-leaves, folded up like fans in such a way that the main veins are on the outside; their stalks are still undeveloped. Buds of larger size will be found to contain flowers within one or two pairs of leaves. Besides stripping off the bud members one by one, transverse and longitudinal sections should be made.

Third, watch what changes take place in a budding axis during the growing season. The scales drop off as the buds open, the inner ones lengthening. From one pair of scales to another is, of course, an internode. These internodes never lengthen, which accounts for the massed scars. But the internodes between pair and pair of the foliage-leaves in the bud do lengthen, and very quickly. The apex of the shoot may be carried up one to two feet before growth in length is suspended. It swells out then into the terminal bud, which is to continue the story in the year to come. This bud will, in its turn, open, shed its scales and leave a girdle behind it. Clearly, now, the distance from scar-girdle to scar-girdle represents the growth made by the shoot in one year. By counting such intervals we can arrive at the age of a branch (Fig. 88).

Comparisons should be made amongst a number of trees, in the matters of the amount of yearly shoot-growth, the number of new leaves, the time when the resting bud is formed, etc.

Experiments may also be made in forcing resting buds into premature activity. It can be done in some cases in summer by stripping the foliage from the shoot, when possibly the extra supplies of water and salts available stimulate growth in the bud-leaves. It must be remembered, however, that the dormancy period of buds, like that of seeds, is generally necessary for their maturing, and that usually they cannot be tempted to open in winter, even when conditions of temperature and moisture are made favourable for them.

Foliage

The leaf of the Sycamore Maple is large and strongly built, dark green on its upper surface, paler beneath. It is cut deeply into five lobes and may be compared with the leaf of the Horse Chestnut, in which the in-cutting has reached the midrib and a compound-palmate leaf has been formed. This and other leaves might be skeletonised to show their venation. Each of the main veins runs out to the tip of a lobe. Find out whether leaf margins are strengthened by harder tissue or by marginal veins. This is one way of preventing their being torn by wind. Another lies in the readiness with which the leaf twists away from wind pressure. A much-divided leaf has an advantage in this respect.

If a leaf is to live and work it must have light. This is not easy to secure for every one of the close-set myriads on a tree, but it is done. The spacing out of leaves along the axis of a shoot helps to secure light for each of them; in the Sycamore two leaves stand at each node and the pairs are at right angles (*opposite and decussate phyllotaxis*). Compare the leader of a sapling or any upright shoot with its radially disposed leaves, with a horizontal shoot from a Beech or a Maple. The latter looks as if it had been pressed between weights until all parts lay in one plane. This makes less the shading of one leaf by another. It also brings the broad leaf-surface into a position in which it will receive as much light as possible, which is usually not too great for it in this country. The alteration in the position of the leaves is brought about in various ways; sometimes the internode twists and swings a pair of leaves through an angle of ninety degrees, as in Beech; sometimes the leaf-stalk bends, as in the Sycamore Maple; sometimes certain of the leaf-stalks are long enough to carry their blades clear of the others, again as in certain Maples. Leaves may be so shaped that they fit into, rather than overshadow, each other; then they form what is often referred to as a leaf "mosaic." In Ivy growing against a wall, the deeply cut leaves dovetail very nicely; on the other hand, upright Ivy shoots, illuminated all round, bear their simple leaves well separated. In Elm the two halves of the leaf-base are not symmetrical and the outward curve of another leaf fits into one of them. In the Deadly Nightshade leaves of two sizes are arranged so as to cover a space completely.

When there is risk of light being too strong for the chlorophyll, leaf-surfaces are placed parallel with the path of the incident rays; this is seen in the downward-pointing leaves of the Eucalyptus of Australia and the upward-pointing leaves of the Olive of the Mediterranean shores.

In extreme cases of danger from insolation, leaves may be reduced to mere scales or spines. The plant, however, must have green tissue; other organs are therefore modified. In some Acacias the leaf-stalk is flattened and widened and green (a *phyllode*); in Butcher's Broom, stems are so altered that they look like leaves (*phylloclades* or *cladodes*) (Fig. 83); in Cacti, the stem remains cylindrical, is green, and is shaded by the ranks of spines, the reduced leaves. In all these modifications, the green surfaces are placed parallel to the path of the rays of light.

In some trees (e.g. Beech and Maple) there are "sun-leaves" and "shade-leaves." The latter are of larger area, but thinner than the former; their chloroplastids are thus kept near the surface to catch all available light. The shade-leaves are often simpler in outline, with a resemblance to the "youthful" leaves of the seedling.

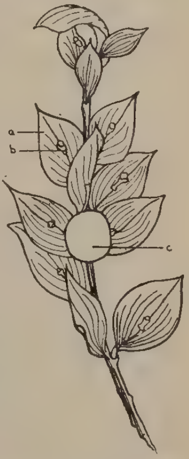


FIG. 83. BUTCHER'S BROOM

a, leaf-like branches (*phylloclades*); *b*, remains of flowers, seated on the branches; *c*, fruit, a berry, its origin not visible.

LEAF-FALL

Under this heading we must not think only of our autumnal leaf-fall but must keep three facts in mind. First, the life of an individual leaf is limited and often short (about three or four years), even in the case of evergreen trees. Second, the deciduous tree of cold temperate regions sheds its leaves at the beginning of the cold season. Third, the deciduous tree of the monsoon regions (i.e. those having alternating wet and dry seasons) sheds its leaves at the beginning of the dry season.

The absence of foliage in winter is highly advantageous to our trees. The transpiring surface gone, the loss of water is negligible. The condition of the winter soil is often one of drought, as far as plants are concerned, even when water is present. This is due to the fact that the temperature is too low for the root-hairs to absorb water (p. 152). The bare tree of our winter and the bare tree of the hot tropical season are alike protected against drought.

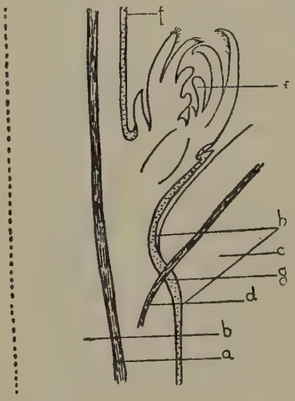


FIG. 84. SYCAMORE: LEAF-FALL
Half the thickness of the branch is shown.

a, vascular tissue of the branch; *b*, pith; *c*, leaf-stalk; *d*, vascular tissue of *c*; *e*, bud; *f*, bark; *g*, separation layer; *h*, point in *g* above which leaf has broken away.

If our broad-leaved trees bore their leaves throughout the year, they might be in great danger during occasional periods of sunny weather in winter when the soil was very cold; water would be lost in great amount and the roots would be unable to make good the loss.

Evergreen trees in the same conditions would not run equal risk, for their leaves are often of small area and their epidermis is thick and heavily waterproofed, whilst their stomata are often sheltered. A second advantage gained by the deciduous tree is that it escapes the damage which might be caused by snow piling up on broad masses of foliage.

Because these are advantages they must not be assumed to be the reasons why trees are deciduous. The causes are related to the cycle of life within the plant cells. All trees must renew their leaves; as leaves grow older they grow less able to do their work well; also there accumulate in them substances such as tannin which are useless within the plant, which are its waste. The leaf which dies and drops, carries these back to the soil, where they may be worked up again for service. The deciduous tree has acquired the habit of doing this annually.

The initial part of the process may be the slowing down of the transpiration current in late summer and the lessening of the water-supply to the leaf. For weeks before the autumn morning when, after strong, heavy rain or sharp frost, we find the roads strewn with leaves, the tree's preparations for the winter have been going on. Those leaf materials which are of value to the plant are withdrawn through the petiole and stored up in certain parts of the trunk and branches (p. 271). For example, nitrogen, potassium and phosphorus are taken into store. Then, at the place of attachment of the leaf-stalk, a specialised plate of cells is formed, closing all communication between the leaf and the branch except by way of the vascular bundle in the stalk (Fig. 84). The cells in the outermost layer of the plate swell up, and the layer is disorganised; it is the *absciss* or *separation* layer; after that the leaf is held only by the frail thread of the vein. The layer of cells interior to the separation layer becomes corky in character; when the leaf drops off, this covers the scar. The break in the vessels of the vein is closed with gum. When all is ready, it needs only a slight touch to detach the leaf.

The chemical changes which take place in the leaf in autumn include changes in the pigments. The green colour of a chloroplastid is due to a mixture of two greens (chlorophyll in the narrower sense) and two yellows. In autumn, light destroys the greens in the normal way (p. 201), but no renewal takes place. The two yellow pigments, *xanthophyll,* then show strongly in the fading leaf. The red tints arise from *anthocyan* (p. 167), also called *erythrophyll.* The formation of the last is favoured by cold, and depends on the presence of sugar. The brown leaf-tints are often traceable to decaying cell walls. Sunny autumn days and slight frosts deepen the autumn colours.

Compare the properties of the yellow and the red pigments with those of the green. Yellow leaves boiled in a beaker of water lose little colour, but when they are boiled in methylated spirit the liquid becomes coloured; that is, xanthophyll is slightly soluble in hot water, but readily soluble in methylated spirit. When red leaves are tested in the same way, it is found that erythrophyll is soluble in boiling water. Extract of chlorophyll was found to be destroyed when exposed to light; after exposure to light for several days the yellow extract is little changed, and the red not at all.

THE FLOWERS

The flowering branch in Sycamore Maple is developed from the terminal bud of a short foliage-shoot, in which the leaves are disposed as usual in pairs. At the end of the season, the whole inflorescence breaks off at the level of the uppermost pair of leaves, making a scar between them. Growth next season is continued by the axillary buds of these leaves, which makes the branching appear to be dichotomous. It is not, of course, and this is only *false dichotomy* (Fig. 81).

The inflorescence exemplifies those more complicated types referred to on page 28. Its main plan is that of a drooping raceme, but it is only at the top of it that you find the solitary stalked flowers of the simple raceme. Numerous secondary axes are given off, and these bear some resemblance to umbels and some to cymes (Fig. 85).

The flowers vary. Some are apparently (may be actually) hermaphrodite, but functionally are pistillate. Some are plainly staminate. The former are placed centrally in the little cymes. All are small and yellowish green. In this they should be compared with flowers of Ivy, Dog's Mercury, etc. The complete flowers have five free sepals, five narrower free petals, eight stamens which rarely open even though they contain pollen. The ovary is superior and two-celled; there are two (occasionally three) united carpels. Each cell contains two ovules, only one of which becomes a seed. The ovary is flattened and hairy, and its coat is drawn out on the outer edges into two thin wings. The style is short, and the two stigmatic lobes curl over and outwards. The other flowers have eight to twelve functional stamens and a sterile pistil. Stamens ripen first. The flower, though lacking the brightness of insect-flowers, provides nectar and is visited by insects. The glandular part is the yellow circular cushion at the base of the pistil. This is a pretty open situation, and Flies and short-tongued Bees avail themselves of it.

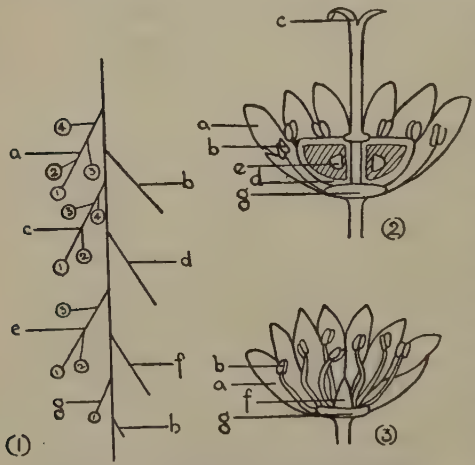


FIG. 85. SYCAMORE MAPLE: FLOWERS

(1) Diagram of inflorescence. The whole is a raceme; each secondary member is a cyme. *a–h* gives the order in which the secondary axes arise; 1–4 gives the order in which the flowers open. (2) Hermaphrodite flower: section. (3) Staminate flower: section.

a, calyx or corolla; *b*, stamen; *c*, stigma; *d*, carpellary wall; *e*, ovule; *f*, abortive pistil; *g*, nectary.

The Fruits

After fertilisation there is a general increase in the size of the fruit, and a very great expansion of the side-wings, until their surface area is many times greater than that of the rest of the fruit. The high ratio of surface extent to weight makes the fruit buoyant; it will fall through air more slowly; it will have a chance of being carried a fair distance in a strong wind, though usually it falls not far from the tree. Try to get data about the average and the extreme distances from the tree at which fruits drop, as well as of the nearness of seedlings to trees. If you can get the opportunity on a calm day, watch how (moving in a spiral) the fruits float down to the ground. Test them, as you did those of Coltsfoot, to see what is the efficacy of the wing-floats.

The fruit usually does not drop as a whole. As it dries, the two carpels split apart and dangle for a little while attached to two filaments at the top of a common stalk. Such splitting fruits are called *schizocarps*. Opening the Sycamore fruit, you find that its coat is thick and that its interior is lined thickly with hairs, a dry and warm bed for the one brown seed. The fruit never opens to permit the seed to escape; the coat rots off at germinating time.

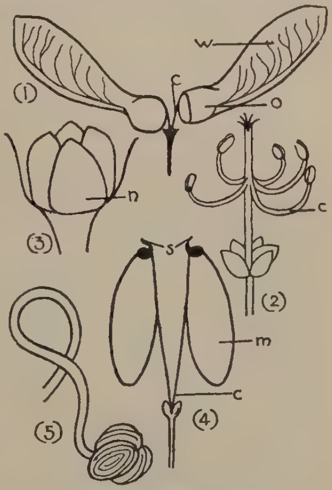


Fig. 86. Schizocarps

(1) Sycamore Maple; (2) Geranium; (3) Labiate; (4) Umbellifer; (5) Nasturtium.

c, carpophore; *s*, stigma; *m*, mericarp; *n*, nutlet; *o*, ripened ovary region; *w*, out-growth from *o*.

This schizocarpous fruit belongs to the *samara* (winged) group of fruits. The Sycamore has a double samara; Ash has a single samara slightly twisted and with the "wing" extending far beyond the seed-case; the Elm and Birch samaras are winged nearly all the way round. These may be compared with Pine, in which it is the *seeds* which are winged. In Hornbeam the wing is furnished by three united bracts to which the fruit adheres; in the Lime-tree a little cluster of fruits is distributed by a large bract. The Dock has a triangular akene; the perianth persists and is extended into three wings.

The group of the *schizocarps* needs a little more notice. Maple breaks into two winged segments, like Sycamore. In some of the

Umbelliferæ (e.g. Hogweed) the bi-carpellary fruit splits into two parts (*mericarps*), each of which swings for a time on a thin stalk. The Cranesbill has a syncarpous ovary of five carpels; the fruit splits into five parts; these are attached to five thin strips of the central axis which split off from the bottom and curl upwards, carrying the fruitlets. Plants belonging to the same Families as Borage and Dead Nettle have a schizocarp which divides into four nutlets. The Garden Nasturtium breaks up into three separate fruits. In Mallow and Hollyhock, the ovary breaks up into a ring of wedge-shaped fruits lying within the persistent calyx (Fig. 86).

Germination

Soak some seeds and examine their contents; nothing besides the embryo is present. The embryo is a particularly long narrow body, but it is cleverly coiled up so as to fit into a rounded cavity. Softened by water it can be gently pulled straight. There is quite a long curved radicle, and two still longer, strap-shaped cotyledons. The latter are folded face to face and then rolled up. The curve of the radicle fits round one side of the roll. The plumule is a very small bud lying between the seed-leaves; the latter are green whilst still inside the fruit-case.

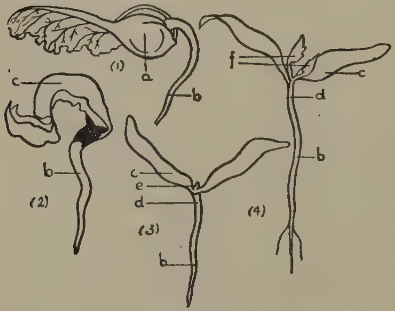


Fig. 87. Sycamore Seedlings

(1)–(4) Four stages of development.

a, fruit coat; *b*, radicle; *c*, cotyledon; *d*, hypocotyl; *e*, plumule; *f*, first and second foliage leaves.

Comparison may be made with seedlings of Beech. The two cotyledons are solid-looking objects. Whilst in the seed they are folded face to face and then refolded like a fan; they are drawn out in rather a crumpled condition. They enclose a downy little plumule.

Sow some "keys," and get a good set of sketches illustrating their development; it is important that you should know how a tree makes its start in the world. The crumpled cotyledons straighten out and fall apart in the air; they do the work of foliage-leaves for some time. The first foliage-leaves are rather slow-growing; they, like others we have seen, are simpler than adult foliage-leaves, being of an elongated oval shape, serrated at the edge, but without lobes (Fig. 87).

A school which studies seedling trees should keep its young plants for several years, in order that each class may be able to compare the growth in a succession of years. Observations should be made from fruiting time onwards, in the vicinity of Sycamore-trees. Try to get an approximate idea of the proportion of fruits from which seeds germinate, and also how many germinations are carried on to the stage of young trees. Notice the particular kind of spot which seems most favourable to seeds, e.g. under a carpet of rotting leaves. Mark a number of seedlings and see if you can discover some of the reasons why seedlings disappear. What animals eat them? Are they likely to be affected by cold or drought? In what months do they appear? If you can visit a tree nursery, do so; there you may make comparisons amongst young trees of different kinds.

Root Systems of Trees

A great wood had been laid low in a single night of terrific storm: in the morning it looked as if a huge hand had been laid against it and had pressed it flat. Along the windward edge the trees had yielded first; in their fall they carried down the lines in front of them; the wave of destruction passed forward; not a full-grown tree escaped. No better demonstration of the root systems of trees could have been imagined. Most of the trees were Spruce, a few were Firs, and there were clumps of Scots Pine. Every tree, as it was riven from its stance, tore up along with its roots a sheet of soil averaging a foot thick. The two extreme types of the root systems found in trees were displayed. In one, well exemplified in the Spruce, the central, tap root is early superseded by secondary roots which radiate from it quite close to the surface of the soil—in fact, such thick old roots may often be seen quite uncovered. The rootlets at their extremities extend outwards just beyond the longest branches and find very convenient the water which drips from these. The storm finds in a tree so rooted a very easy victim. In the Fir, on the contrary, the tap-root persists and runs down to a depth of many feet. The Scots Pine has a variable system of roots; when the water-supply is near the surface, horizontal roots are profuse; when water has to be sought farther down, the tap-root goes after it and may be accompanied by some of its many strong secondary roots. Beech possesses extensive surface roots, Oak a long tap-root; Walnut has both.

In the wood referred to above, the gale was so fierce that trees with all types of roots were overturned. In other cases, only the shallow-rooted trees are seen to be destroyed; the deeper-rooted remain standing.

The mycorhizal associations of trees are described on page 140.

CHAPTER XX

SECONDARY TISSUES IN TREES

Opportunities should be sought to examine timber which has been felled recently. Make sketches of the cut ends of tree-stumps; compare sections of the bole with sections of branches of different sizes which have been lopped off. This will give an idea of the alteration which takes place in the wood of a tree as it grows older. Compare together, if possible, stumps of Sycamore, Oak, Beech and Willow. Procure specimen sections of branches of at least Sycamore Maple, Oak and Lime; one section of each should be transverse, one longitudinal and through the centre (radial), and one longitudinal and tangential; examine these in detail with the simple lens. For further detail, microscope preparations will be necessary.

The bulk of the tree is, of course, lignified tissue. Surrounding this is what may be called the rind; the outer, more compact part of this is bark; a narrower belt of paler colour and softer texture lies adjacent to the wood. The massive trunk represents the result of long-continued secondary growth such as is described on pages 194, 195. The wood of the tree is the xylem; the belt of softer tissues just outside it is made up of cambium, phloem and possibly cortex; the rest outside this, the bark, is the product of the activity of cork-cambium. The wood may extend to the very centre of the section, or there may be still evident a tiny representative of the original pith. Radiating lines, of lighter colour than the rest, cross the wood; they all start from the circumference of the stele, but only some of them reach the inner limit of the wood. These are the medullary rays; they are very well marked in Lime. In a cross-section the rays appear as narrow streaks; a radial section shows them to be vertical plates of no great depth; and a tangential section exposes their ends as long, thin, lens-shaped areas.

Procure a branch of Sycamore in which three years' growth is present. Take a section from the growth of each of the three years; they will show marked changes in the relative extent of cortex, vascular tissues and pith—the great gain lying in the xylem (Fig. 88).

The greater part of the wood of a tree consists of the wood fibres typical of xylem; the narrower of the xylem vessels supplement these as strengthening tissue. The vessels in a tree may attain to some feet in length, though the average is a few inches. The fibres have extremely thick walls, narrow cavities and long, tapering ends.

In many trees the wood is very plainly divided into concentric zones. Each zone is graduated in texture and in colour from inner layers of more open wood to outer layers of much closer grain. In the Oak, the unaided eye can distinguish many tubular cavities in the former; in other trees the lens shows that what look like pin-pricks are finer tubes. They are xylem vessels. In the outer layers of these zones the tissue is very compact, the vessels are small, and fibres are numerous (Fig. 89). The wide, comparatively thin-walled vessels are those formed in spring. There is then plenty of water and salts available for quick building up of wood, and the specially wide channels are ready to carry up quickly the rush of sap to the opening buds. The very narrow, thick-walled vessels at the opposite side of the zone are those formed in late autumn, when water is rising less freely in the tree. Next spring the cambium places alongside of them another line of wide-mouthed tubes. There is a gradual transition from spring to autumn wood, but an abrupt transition from autumn to spring wood. Between the two boundaries of the zone is included the growth in thickness which has taken place in one year. Each zone is therefore named an *annual ring*; with various allowances for accident, etc., the rings can be used to determine the age of a felled tree. Oak and Ash possess very large spring-formed vessels. In Maple they are not pronounced; the well-marked line in this is the narrow zone of autumn wood, which is composed almost wholly of fibres. The characteristic "graining" of timber is derived from the

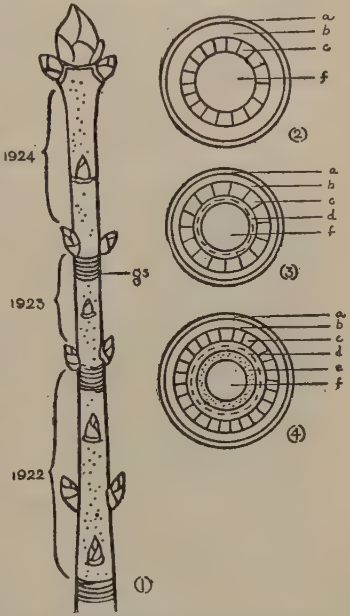


FIG. 88. BRANCH OF SYCAMORE SHOWING THREE YEARS' GROWTH

(1) Years of growth indicated by girdles of scars; (2), (3), (4) Sections made through branch in wood of 1924, 1923, 1922.

a, bark; *b*, phloem; *c*, wood of 1924; *d*, wood of 1923; *e*, wood of 1922; *f*, pith; *gs*, girdle of scars.

distribution of the medullary rays and the annual rings; it varies with the direction in which the wood is cut.

The amount of xylem formed every year from the cambial layer is enormously in excess of the phloem; no great changes occur in the latter.

The original cortex may be destroyed altogether. It cannot increase as fast as the interior is increasing; neither can the epidermis; provision for secondary growth in this region is therefore made. A second cambium arises, the *cork-cambium*. It may originate in any of the layers from epidermis to pericycle. The cells which become embryonic may form a ring, or they may form oval, surface areas, or they may be scattered as numerous small patches. They are brick-shaped and divide both radially and parallel to the surface of the branch. The new cells on the outer side of this cambium soon lose their vitality; their walls are *suberised* (changed into cork). Such cells do not permit water or air to pass through them, hence all tissues external to them dry up and shrink. If the cambium is deep-seated, this may involve the whole cortex. The mass of shrunken tissues forms the bark of the tree. Generally the new cells cut off from the inner side of the cambium are changed into cortical tissue. Sometimes the first cambium functions throughout the life of the tree, as in the Beech, in which it is formed from the epiderm. Beech bark is nearly permanent, only small flakes scaling off. Massive bark is derived from deep-seated cambium. Generally one cambium is replaced by another, which forms in a deeper layer; several may succeed each other. The pressure exerted from within by the growing wood rends the bark; it may fall off in scales as in the Plane, in rings as in Birch. It may remain smooth as in Beech, or become deeply furrowed as in Ash and Pine.

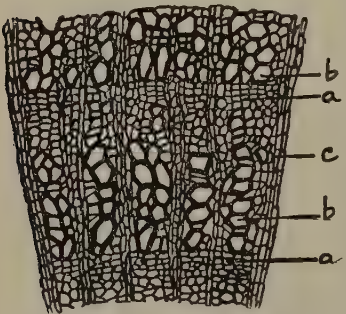


FIG. 89. ANNUAL RINGS: LIME
a, autumn wood; *b*, spring wood; *c*, medullary ray.

When young bark replaces the epidermis of the shoot, it is generally furnished with passages through it which serve the same purpose as did the stomata. These are the *lenticels*; they often arise beneath stomata. On a twig (e.g. Birch) they appear as minute areas of broken surface. They are pores filled with loosely arranged cork cells; in winter they are closed by ordinary cork tissue. In older, thicker bark they lengthen into canals, easily penetrated by air; they are seen in bottle-cork, where they ought to run transversely (Fig. 90).

At the places where branches leave a stem, their cylinders of woody tissue are seen breaking across the stem-wood; they form the larger knots in wood. Smaller irregularities of the same kind, possibly ending blindly within the wood, are the wood-strands of dormant buds. They are styled *eyes* (e.g. in some Maples).

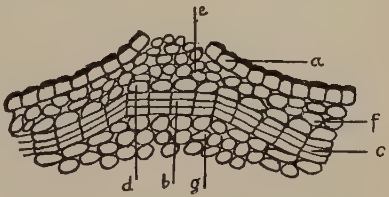


Fig. 90. Lenticel (Diagrammatic)

a, epidermis; *b*, cambium of lenticel which has joined *c*; *c*, cambium of bark; *d*, cells produced from *b*; *e*, *d*-cells suberised; *f*, bark; *g*, cortex.

The tree heals its own wounds, such as those made by the breaking of a branch. The active agent of healing is the cambium exposed at the edges of the break. It at once begins to produce a special wound tissue called *callus*. From all sides this grows inwards until in a small wound its edges meet. Then the meristematic cells form cork on the outside and wood on the inside. If the wound is extensive, cork and wood are produced as cushions along its edges. This is repeated with roll after roll of new tissue until the centre is reached and the whole is covered over. The formation of the permanent callus tissue is a slow process; as a temporary measure of safety the cells all over the wounded surface form of themselves a corky substance which seals them up. It resembles the brown alteration in tissue which appears on the cut surface of a potato.

As a tree matures, a variable proportion of its wood may become incapable of functioning as a conducting tract for water. This area lies in the centre. The wood vessels become blocked; the tissue grows harder and darker. It is known as *heart-wood*; the outer, softer layers, in which the sap continues to flow, form the *sap-wood*. It is the heart-wood which makes durable timber. Oak and Pine form heart-wood; Beech and Spruce do not. The heart-wood in Willow rots, leaving a hollow.

Vegetative Propagation

In the course of our study of plant histories we have become acquainted with many ways in which plants can be multiplied without having recourse to seeds—by the detachment of some vegetative part of the plant. We may summarise these ways: (1) Bulbs and corms produce new plants through buds. (2) Tubers are modified parts of branches; from them originate new plants.

(3) Tuberous roots, both ground and aerial, are of great importance in carrying on the generations of Lesser Celandine. (4) Runners are prostrate, creeping aerial branches; plantlets arise at their nodes. (5) Rhizomes are travelling subterranean branches from which upright "stocks" are sent above the ground as plants. A variation is seen in the "suckers," long, slender shoots striking upwards from the roots of Poplars, etc. (6) In some water plants like Canadian Pondweed, multiplication is a very easy matter, for any piece broken off from the stem is able to start another plant. (7) In Frogbit, Water Soldier and a few other water plants, little buds are detached at the end of the season, sink to the bottom of the water and sprout next season. Lady's Smock, when growing in very wet places, may also shed axillary buds which root in the ground. (8) In some Ferns, little plants are formed on the fronds and thrive, seated on these, for a long time.

The above are all natural methods of propagation; the gardener has ways of his own. He makes use of a principle often illustrated in plant life, which determines that when a plant suffers mechanical injury, tissues which had ceased to grow resume their activity. As examples we have these: when Willows are "pollarded" (i.e. deprived of their main branches), many thin whip-like shoots spring from the "stool," either from dormant buds or from new adventitious buds; as the result of injury caused by a fungus, great brushes of small branches (witches' brooms) are formed on trees; hedges and trees are clipped and polled to encourage bushy growth; the gardener nips out the terminal bud of a herbaceous plant to encourage growth in the lower buds.

Division. From many herbaceous perennials (e.g. Michaelmas Daisy, Primrose, Iris, Delphinium, etc.) the gardener gets two plants in place of one by slicing a plant through the middle. These plants have plenty of nutriment stored in their thick stocks.

Cuttings. Almost any part of certain plants, including an inflorescence, will strike root if given favourable conditions. Stems are the most generally successful.

Trees and shrubs are very commonly propagated by branches; examples—Gooseberry, Privet, Vine, Hop, Clematis. If the gardener is dealing with a Blackcurrant bush, he makes his cutting about November, selecting well-ripened wood of the current year's growth. A length is removed by a sloping cut just below a node, and is trimmed back at the top to eight or ten inches. It is planted in a shady border in firm soil containing a large proportion of sand; this secures close contact of soil with roots, and at the same time is less likely to cause rotting by water lodging round the cutting. To obtain good roots the soil must be well aerated. A little more than a third of the cutting should be buried; before putting it in, the buds at the nodes to be buried should be removed if " suckers " are to be checked. The woody plant has considerable reserves stored in it; hence it soon forms *callus* (p. 233) to protect its wounds, and also sends out adventitious roots from the lower nodes.

Herbaceous plants require different treatment, because their reserves are more slender. The herbaceous cuttings are best taken about September. They are placed in warm, moist soil, and precautions are taken that they do not lose too much moisture from the leaves (the woody cuttings were leafless) before the roots get to work—e.g. shades are placed over them, and some of the lower leaves are removed. Herbaceous plants from which stem-cuttings are taken are Pansy, Pelargonium, etc.

A potato which is divided into pieces (*sets*) and planted is really a branch used for propagation.

Layering is a variation on the method of cuttings. The branch to be used is bent down under the soil and pegged in. On the under side of the bend a partial division of the branch has been made, either by cutting a thin strip off all round (*ringing*) or by a diagonal cut. The result is that whilst the branch is still getting some support from the parent plant, the food manufactured by its leaves tends to accumulate on the branch side of the cut and is used up there in the formation of adventitious roots. When these are well established, the branch is completely severed. This method is practised with Carnations, climbing Roses, Clematis, Currants, " stocks " of Apple, Pear, etc., to be used for grafting.

The number of plants which can be depended on to produce adventitious buds from root-cuttings is small. It includes Pelargonium, Anchusa and Oriental Poppy. Still smaller is the number which, from their leaves—thick, soft, juicy—can supply what is needed to start a plant. It includes Begonias and Gloxinias. A healthy leaf is chosen, its midrib is cut half through and it is placed on damp sand in a moderate temperature and in air which is moist. In the neighbourhood of the cut, roots are formed and fix themselves in the soil; then a bud grows upwards and expands. This case differs from the other two in that both stem and root systems have to be started from the cutting.

The Hydrangea is an instance of a plant from which you may obtain a new individual by using a flowering branch as a cutting. Recent experiments in research stations show that very free-rooting cuttings can be got from underground shoots of some plants.

Grafting is widely practised with fruit-trees; it is a method confined to woody Dicotyledons. It consists in transferring a shoot (the *graft* or *scion*) from one plant to the stem of another plant (the *stock*). Advantages of various kinds are secured by this union of two plants. The health and the disease-resisting power of the producing tree may be improved, its fertility may be increased, its period of ripening may be hastened, its habit of growth may be controlled (e.g. made dwarf, if desired). Tender varieties of Roses are grafted or budded on hardy Briers. To secure a dwarf tree which produces early fruit it has been customary to graft Pear on Quince; this has sometimes been a failure, and search is now being made for "stock" Pears on which fruiting Pears may be grafted. One species may be grafted on another (e.g. Peach on Plum), but the two species must belong to the same Family. The relationship between stock and scion is being investigated thoroughly; it has long been known that the stock has an influence on the scion, but only recently has it been found out that the scion may change the character of the stock.

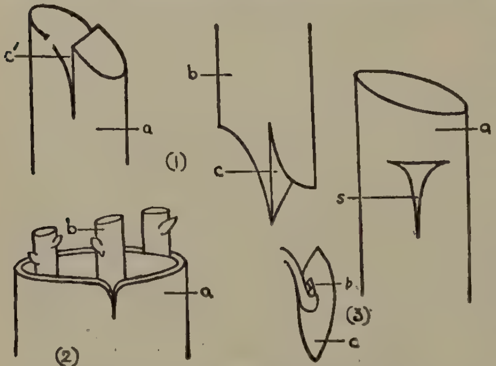


Fig. 91. Grafting and Budding

(1) Tongue-grafting; (2) Crown-grafting; (3) Budding. *a*, stock; *b*, scion; *s*, slit in bark; *c*, in (1) fits into *c′*; *c* in (3) fits into *s*.

Preparation for grafting must begin in January or February, before the sap is moving upwards. The scions should be cut off and placed in garden soil; they should be good shoots of the previous year bearing two to four buds. The stock should about the same time be shortened down to a little above grafting-level. Actual grafting is done about March. Various methods are in use, two of which may be outlined. In *tongue grafting* two slanting surfaces in stock and scion are exposed and then bound face to face. Previously the lower end of the scion, which has been trimmed down to about three inches in length, is cut on a long slant; then the cut surface is notched. The end of the stock is cut and notched similarly; then the two are fitted accurately, notch within notch, and the barks in contact. The union is bound round with strips of raffia, and a coating of grafting wax is applied; this is a preventive of rotting and of fungal growth. It is essential that the cambium of the scion and the cambium (p. 194) of the stock should come into contact and become fused. New conducting tissues form across the junction, and appear to begin early to operate in the conveyance of water, etc. The further treatment of the grafted plant includes the rubbing off of shoot-buds which arise on the stock, and the loosening of the wrappings as growth proceeds.

Crown or cleft grafting is employed when the stock is much thicker than the scion. The scion is prepared in nearly the same way, but the stock is cut transversely, and one or (generally) more scions are fixed into it from above. The end of the scion is made wedge-shaped and the cut in the stock corresponds. (Fig. 91.)

In **Budding,** the scion is reduced to one bud and a small area of bast, cortex and epidermis adjacent to it. It is a method much used in establishing Roses. The English Brier—either cutting-reared or seedling-reared—is used for a stock in some districts, and the Manetti, an Italian Brier, in others. Budding is done in July and August; the Briers should be selected and shortened in the previous November. They must be deprived of all but about three of the best shoots. Budding is carried out when these shoots reach the stage when bark separates easily from wood. The buds chosen for transfer are those of medium age growing about the middle of a shoot. They must be cut out with extreme care. The leaf subtending the bud is cut off so as to leave about an inch of its stalk. A sharp knife is inserted half an inch below the bud (the tip of the shoot being held bent towards the operator) and a slanting cut made inwards and upwards, coming out half an inch above the bud; this removes a thin " shield " of tissue carrying the bud. Any shaving of wood which may back the shield is taken away very carefully, avoiding the removal of the core from the bud. The Brier stock is prepared by making a T-shaped cut through the bark of the shoot near the junction of the shoot with the stem. The bark is opened gently and the shield slipped in down to the base of the cut. The bit of shield which projects above the T-cut is removed. The bast with the adjacent cambial layers, in both the bud and the rind of the stock, are brought into contact, and when they grow form a tissue common to both. The whole is bound up with raffia and afterwards protected from desiccation. After the bud has shown growth the Brier stock above is cut away.

Tree.	General Form.	Branching.	Twigs.	Bark.
Oak.	60–150 feet, very wide crown. Massive trunk. Leader lost.	Wide-angled. Great horizontal spread of lower branches Branches gnarled, angular.	Wide-angled, clustered, angular.	Rugged, meshwork of deep cracks.
Beech.	Up to 120 feet. Wide-based cone, in open space. Tall straight trunk. Leader distinct for a time, then growth by lateral buds.	Steep-angled. Large, low-placed branches, in open. Dwarf shoots present.	Narrow-angled, numerous, slender. Regular, parallel arrangement. Sheds twigs.	Smooth, grey, thin.
Common Elm.	125 feet. Tall, stately. Broad dome, empty crown.	Sympodial branching. Large horizontal branches, in open. Branches at higher level, in wood. Dwarf shoots. Suckers from roots.	Wide-angled. Fine tracery. Cork-covered. Hairs on very young twigs. Sheds twigs.	Grey to brown. Deeply furrowed.

OF COMMON BRITISH TREES

Buds.	Leaves.	Fruit.	Habitat.	Tree.
Numerous, sessile, plump, smooth with rounded tips. Bud-scales are stipules of leaves which do not develop.	Flattened foliage masses. Spiral arrangement. Oval, sinuate.	An acorn, cupule of fused scales.		Oak.
	(1) *Quercus Robur.* Petiole short or absent. Leaf-base auricled. Few simple hairs on under surface.	Long-stalked acorn.	Damp, heavy clay and loam.	
	(2) *Q. sessiliflora.* Petiole longer. Leaf-base tapering. Many branched hairs.	Acorn sessile or with short peduncle.	Drier, more sandy soil.	
Long, narrow, tapering. Bud-scales are stipules, numerous, in pairs. Inner scales have green leaves between them, outer have not.	Tiers of foliage. Very deep shade. Foliage may sweep to the ground. Arrangement alternate. Entire, oval, smooth and lustrous above. Pale green and edged with hairs when young. Fine autumn colour.	Two triangular nuts in spiny woody cupule formed from bracts.	Shade-enduring. Native in south-east England. Plantations succeed on many soils.	Beech.
Small, roundish. Outer scales single, inner in pairs. Scales are stipules of leaves which develop a blade.	Tiers of foliage. Deep shade. Arrangement alternate. Dark green, roughly hairy above, softly hairy beneath, ovate, pointed, toothed, asymmetrical.	Never germinates in Britain. A samara in which wing surrounds fruit. In bunches.	Often in hedges.	Common Elm.

Tree.	General Form.	Branching.	Twigs.	Bark.
Ash.	Up to 120 feet. Crown oval, narrow, rather open. Leader lost.	Steep-angled. Often divides into several large limbs near ground. Branches may droop heavily. Dwarf shoots.	Few, strong, stiff, with upturned tips. Smooth, grey-green.	Light grey Smooth for a long time. Fissured when old.
Birch (*Betula alba*).	40 to 50 feet. Graceful, conical. Leader distinct to the top.	Slender. Steep-angled.	Acute angles. Slender, drooping, delicate sprays. Dark colours. Resinous warts. (In the Common Birch, young twigs are hairy.)	Coarse dark brown at base of trunk. Pale grey above. Cast in silvery-white sheets or thin rings.
White Poplar.	Tall. Irregular oval crown. Leader lost.	Lower, very wide-angled. Strong. Dwarf shoots. Numerous suckers.	Acute angles. Grow straight out. Young with downy hairs, older smooth.	Smooth, grey, furrowed when old.

Buds.	Leaves.	Fruit.	Habitat.	Tree.
Terminal much larger than lateral. Blackish, blunt pyramids. Bud-scales are leaf-bases.	Shade not deep. Light masses of foliage. Leaves opposite and decussate, sometimes alternate. Compound pinnate; leaflets lanceolate, acutely pointed, toothed.	Single samara. In clusters.	Not shade-enduring. Limestone soils of north and west of England. Wet woods of fens.	Ash.
Ovoid, pointed. Scales are stipules.	Foliage in sprays. Throws little shade. Arrangement spiral or alternate. Small, ovate, serrate, broad-based. Stipules are scales.	A small delicate winged nutlet. Grouped as catkins.	Requires much light. Hardy; in cold latitudes, in high valleys, in peat soils.	Birch (*Betula alba*).
Sessile, plump, pointed, hairy all over.	Foliage in light drifts. Spiral arrangement. Broad ovate, or cordate, wavy margin, smooth upper surface, white hairs on lower. Petioles flattened sideways.	Slender capsules. Grouped as catkins. Seeds with hairs.	Good moist soil. In hedges.	White Poplar.

Tree.	General Form.	Branching.	Twigs.	Bark.
Lombardy Poplar.	100 to 150 feet. Tall slender spire. Trunk twisted and ridged. Leader lost.	Steep angle. Sympodial axis. Numerous fine branches almost perpendicular. Suckers from roots.	Angles acute. Smooth shoots. Twigs shed.	Rough. Deep furrows.
Horse Chestnut.	70 to 80 feet. Leader distinct to the top. Wide cone or pyramid. Stout bole.	Wide-angled. Fine series of curves. Droop under weight. Branches thick, heavy. Tips curve upwards.	No fine twigs.	Becomes furrowed and scaly.
Common Lime.	80 to 90 feet. Tall straight stem. Empty crown. Wide girth of bole.	Steeply ascending. Many large branches. Many stool shoots. Sympodial axis.	Wide-angled. Point upwards, zigzag. Long, slender, numerous. Red.	Smooth, brownish. In age, darkens and becomes fissured.

Buds.	Leaves.	Fruit.	Habitat.	Tree.
Long, pointed. Sticky before opening. Scales are stipules.	Foliage in narrow, oval, upright masses. Spiral arrangement. Small, rounded, green on both sides. Deciduous stipules. Petiole flattened laterally.	Capsules. Seeds with hairs.	Good moist soil. In hedges. Ornamental tree.	LOMBARDY POPLAR.
Paired. Large, full oval, brown, sticky with gum and resin. Scales are leaf-bases; bear hairs.	Rounded, dense foliage-masses. Opposite and decussate arrangement. Large, compound palmate. Large shield-shaped leaf-scar.	Spiny capsule. One large seed, usually. Splits into three valves.	Not native. Ornamental.	HORSE CHESTNUT
Short, rounded, reddish. Two outer scales not paired. Inner paired, are stipules of foliage-leaves.	Tiers of leaves. Alternate arrangement. Cordate, unequal sides, thin, smooth, serrate.	Rarely fertile in this country. Globose nuts. Wing formed from persistent bract.	Not native. Ornamental.	COMMON LIME.

Tree.	General Form.	Branching.	Twigs.	Bark.
WILLOW.	A. *Palm or Goat Willow.* Tree under 30 feet. End bud dies. B. *Osier.* End bud dies. C. *White Willow.* 60 to 80 feet. Wide mass.	A. Sympodial branching. B. Coppiced to produce slender shoots. C. Wide-angled. Branches near base.	Slender, upright, smooth.	Smooth, becomes irregularly fissured in C.
ALDER.	Generally short and bushy but may grow to tree size. Leader lost. Clusters of nodules on roots.	Wide-angled. May divide into large branches near ground. Many stool shoots.	Short, stiff, angular. Reddish when young, also sticky. Large lenticels.	Smooth till old, then fissured, ridged and nearly black.

Buds.	Leaves.	Fruit.	Habitat.	Tree.
All sessile, small, pressed against stem, covered with one scale which equals two fused leaves.	Spiral arrangement. A. Reticulate, broad oval, stipules half-reniform, green above, soft white beneath. B. Long, very narrow, entire, silky under surface. C. Lanceolate, acuminate. Silky white on both sides. Stipules deciduous.	Capsule, opens into two valves. Grouped as catkins. Seeds with hairs.	A. Hedges. and woods B. Wet ground by streams and lakes. C. River-banks. All in open situations with deep moist soil.	**Willow.**
Stalked. Large, angular, dark reddish brown. Bud-scales are stipules; waxed together. Whole bud enclosed in stipules of oldest leaf, then each leaf provides stipules.	Foliage uniformly distributed. Spiral arrangement. Obovate, rounded apex, serrate. Stipulate until mature, with sticky hairs when young.	Female catkin becomes woody. Dry, one-seeded nutlet. Fruit wall is spongy.	Light-demanding. Wet situations. Tree form in good loam.	**Alder.**

The flowers of the trees in the above tables are generally inconspicuous and simplified in their parts. Those of Willow and Poplar are described on page 307. In Hazel, Birch, Alder, Beech and Oak the flowers are unisexual; the two sexes are borne on the same tree. There is a small epigynous perianth and a one-celled ovary of two carpels; stamens are variable. The inflorescence is often a catkin and bracts are conspicuous. Wind-pollination is the rule. The flowers of Elm, Ash and Sycamore are hermaphrodite. The perianth may be fairly well developed. Horse Chestnut has a very showy perianth.

Conifers

The principal trees belonging to this Family which are common in Britain are the Spruce (*Picea excelsa*), the Silver Fir (*Abies pectinata*), the Scots Pine (*Pinus sylvestris*), the Larch (*Larix europæa*), the Yew (*Taxus baccata*), and the Juniper (*Juniperus communis*). The Spruce and the Fir are perfect examples of trees in which the main axis of the seedling maintains its supremacy throughout the life of the tree, whilst the branches of the first order are almost geometrically graduated in strength and length from the lowest to the highest levels. When growth is not interfered with, such a tree has the symmetry of a broad-based cone. Another feature is the tabular arrangement of the foliage, gained by various adjustments in twigs and leaves.

The Scots Pine departs far from this form. Its " leader " is lost fairly early; its foliage is in bunches rather than sheets; its massive old branches occur rather irregularly and they break off so frequently that the broad heavy crown may surmount an ungainly length of stem. In the Pine of the third year, the apical bud of a shoot is surrounded by several buds which develop into false whorls of branches. A Pine bears both long shoots and dwarf shoots. The dwarf shoots are of a type quite peculiar to it; they are exceedingly short, and, besides scale-leaves, bear only two needle-like foliage-leaves at the apex; they are " bifoliar spurs." Its old bark is rough and dark, its younger bark is yellowish and thinner (Fig. 92).

The Larch rises as a graceful cone of open foliage with a sweeping curvature in its branches, and a graceful droop in its twigs. It possesses both long and short shoots; bud development is often irregular; its bark is brown, easily separable into scales and deeply furrowed longitudinally.

The Yew, a characteristic tree both of the chalk of south-east England and the limestones of the Pennines, grows to no great height, though it is long-lived. Its gnarled, twisted stem breaks up into branches close to the ground; sometimes new shoots coalesce with an old stem and a very massive trunk is the result. Growth is very slow and the wood is strong and elastic. It casts a dense shade. Its bark is reddish and flaky. Juniper is a shrub or a shrubby tree found often on our higher land, including the limestone fells. Its bark resembles that of Yew.

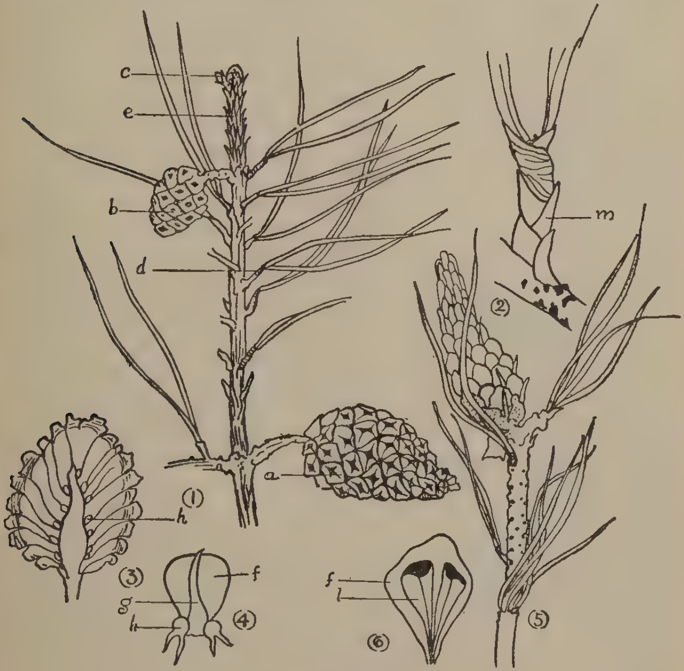


Fig. 92. Scots Pine

(1) Branch showing cones of three different years; (2) Dwarf shoot and bases of pair of leaves; (3) L.S. of female cone; (4) Scale from (3); (5) Male cone; (6) Scale from (5).

a, cone of 1923; *b*, cone of 1924; *c*, cone of 1925 near end of long shoot; *d*, dwarf shoots of 1924; *e*, scale leaves; *f*, bract; *g*, succulent scale, placental; *h*, ovule; *l*, pollen sac; *m*, scales of dwarf shoot.

All the coniferous trees are evergreen except the Larch, which has narrow soft green leaves. The foliage is strikingly xerophytic. Leaf area is always greatly reduced, the leaves being long and very narrow. Except in Larch the epidermal cells are heavily waterproofed with cutin, and the cuticle is thick. The guard-cells of the stomata are generally sunk beneath the epidermal surface-level; details vary in the different trees. Resin ducts are often present

(Fig. 93). The needle-leaves of Pine are borne in pairs on short shoots with scaly bases; such a shoot is shed as a whole at the end of two or three years of existence. On the long shoots of Pine, only scale-leaves are formed. Larch leaves are clustered on dwarf shoots. Silver Fir has flat leaves, Spruce has quadrangular; both are carried on long shoots.

The wood of Conifers is simpler than that of woody Dicotyledons; there are no vessels and no fibrous cells. The whole wood-mass consists of narrow, thick-walled cells (*tracheids*) which serve both as water-conducting and as strengthening tissue; their walls are pitted (Fig. 72). Water moves much more slowly through the tracheids than through vessels; with this fact may be correlated the xerophytic foliage which prevents water from leaving the tree too freely. In the timber of Conifers annual rings are very distinct, the autumn wood being dark brown or reddish, and the spring wood soft and pale. Spruce and Pine have resin ducts in the autumn wood. Heart- and sap-wood are of the same colour in Silver Fir and Spruce; in Larch and Scots Pine the heart-wood is ruddy brown and the sap-wood yellowish.

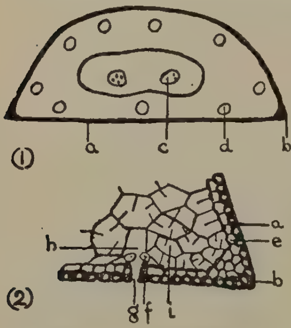


Fig. 93. Scots Pine

(1) Diagram of leaf; (2) Details of epidermis of leaf.

a, epidermal cells with excessively thick walls; *b*, strengthened edge; *c*, one of the two vascular bundles; *d*, resin canal; *e*, thick-walled hypodermis; *f*, sunken guard-cell; *g*, entrance flanked by two long epidermal cells; *h*, stomatal chamber; *i*, ground tissue with infolded cell-walls.

All the Flowering Plants hitherto considered have had their ovules enclosed in an ovary; they form the great group known as the *Angiosperms*. The Conifers belong to the group of the *Gymnosperms*, in which the ovules are carried "naked" on a carpellary scale. Fruit is formed in the first group, but not in the second. Reproduction as it is seen in the Scots Pine will serve as illustrative for the group. The reproductive organs are massed in cones; the cones are unisexual and in Pine (but not in all Conifers) the two sexes occur on the same tree. The group of male cones stands near the end of a branch, and the female as a lateral bud very near the end. The male cones consist of stalked clusters of stamens grouped round a leaf-tipped axis; each stamen has its two pollen-sacs. Immense quantities of pollen are produced. The young female cone shows on its exterior a spiral of overlapping scales. When the cone is opened out, each of these is found to be subtended by a smaller scale The larger of each pair is a functional carpel and bears on its upper surface, near its insertion, two ovules. Here we have the simplest form of a female flower we could conceive of—an ovule and the structure from which it springs. It is a form of great antiquity. Pollen is carried by the wind from cone to cone and drifts in between the partially opened scales. It is curious pollen, each grain rendered buoyant by two balloon-like expansions of its coat. The grains settle on the micropyle of the ovule, but actually fully a year elapses before the pollen-tube carries out the act of fertilisation. Possibly the seed matures and is shed during the same autumn, possibly not till next spring (Fig. 92). Then the scales spread apart, the seeds are shaken out, and, as they are "winged," they are likely to float some distance. The seeds contain endosperm which acts as a food reservoir for the cotyledons after germination; their tips remain in contact with it. There are several cotyledons. There are interesting features in the seedling, which for two years bears only narrow green leaves.

In the cones of the other trees there exist minor differences. In Yew, the female structure is very different. One ovule arises as an axillary bud provided with a few scales. At seed stage there grows up round the seed a green cup which ripens into the red Yew "berry." This is an excellent example of one form of an *aril*, or outgrowth from a seed (Fig. 15).

CHAPTER XXII

WOODLAND

When bare land is colonised by plants, in the course of years, one type of plant community succeeds another until a stable condition is established which forms the *climax* for that particular soil and climate. The two great Plant-formations of the world are grassland and forest. The factors which determine which is to prevail are complicated. Trees require great supplies of water; their great root systems enable them to seek for it at great depths, hence they are not usually dependent on rain falling at a particular season. Strong, drying winds are most hostile to tree-growth. The shallow-rooted grasses are dependent on the surface soil and must have rains which will keep that moist in the growing season. Their lowly growth makes them indifferent to winds. The violent and frequent north-west winds probably have decided that it should be prairies and not forest in the central plains of North America. Forest and grassland are *closed* communities; desert is an *open* community, a climax form in which the limiting factor is scarcity of water.

When plants grow in close company they interfere with one another's functions; there is, however, often evident a mutual accommodation which lessens this interference. Both principles are illustrated in a wood. To understand the wood community we must keep in mind the following facts: the tree is long-lived, which tends towards the permanence of the forest; the enormous amount of water lost from the soil through transpiration; the ability of the tree-roots to travel deep or travel wide in search of water; evaporation of water from the soil is hindered by the tree-canopy; the varying but often great decrease in illumination within the wood; plants growing under the trees are protected from wind; the great amount of vegetable debris, especially under deciduous trees, which collects on the forest floor; the formation of a highly peculiar forest soil (p. 252).

The student must note these generalities, but the student must also go to the wood and make first-hand acquaintance with them, and for that some guidance may be helpful.

Local residents may be able to supply information about the history of the wood selected; practically no British woods are "natural"; they are plantations, the age of which should be ascertained. The altitude of the situation, the aspect, the slope of the ground, the exposure to wind should all be noted. The character of the underlying rock is of the utmost importance, e.g. limestone or sandstone; a geological map should be consulted and rock-exposures should be examined.

Thorough survey of a wood requires much time and trained experience, but a simple outline of the distribution of its vegetation is not beyond a young student. The information collected may be set out in the form of a chart, symbols being assigned to the principal plants. Lists of species should also be made. If there is choice, take a wood in which more than one species of tree is present and compare the vegetation growing under them. One of your charts (A) may be reserved for physical features—changes in slope, an outcrop of rock, a ditch, a stream, a pool—some of which may be well-defined subordinate habitats. A second chart (B) may be necessary, on which to set out changes in soil. The soil notes should indicate, as far as is ascertainable, depth of soil (e.g. variability on sloping ground), mineral character, humidity, amount of litter (undecomposed leaves, etc.), and amount of humus. The vegetation chart (C) will show the relative abundance of the chief species of tree, shrub and ground plants in different parts of the wood.

By correlating A, B and C, some direct causal connections may be made out, e.g. a change in the tree species or in the ground carpet may be clearly due to change in depth of soil or in the amount of soil-water. The utmost caution, however, must be observed before coming to conclusions of this kind; the obvious is not always the ultimate cause.

The tree dominates the woodland association mainly by fixing the amount of illumination within it; the degree of shade depends on the thickness of the canopy and the closeness with which the trees are planted. A rough estimate of the loss of light within the wood as compared with the exterior of the wood may be got by testing with one of the actinometers used in photography. That sequence of ground vegetation as regulated by decrease in illumination which unfolds in spring in deciduous woods, must be studied.

Where shade is not too deep, as many as four tiers of vegetation may be present in a wood—the trees, the shrubs, the herbaceous plants, the ground Mosses, etc. Dense shade may reduce these to the tree and the moss tiers, or even (as in a Spruce wood) to the trees. The feeble light within the wood is most unfavourable for flowers; it suits exceedingly well Mosses and Ferns.

The rain forest of the tropics is an extreme and fascinating example of the dim forest-world. There, is to be seen a literal scramble for light. The dense tangle of plants fighting with every conceivable contrivance of hook and twist and coil to get up to the realms of light, illustrates vividly the way in which the habit of the climbing plant originated. Our forests lack the moisture and the heat required for such luxuriance of tall growth; we find in their depths no climbers except Honeysuckle and Ivy.

The rain forest, too, shows how the *epiphyte* came into being. They are there in multitudes—on trunks, on branches and even on leaves; they include numerous handsome flowering plants, particularly Orchids. The epiphytes of our woods are the Polypody Fern, Mosses, Liverworts, Lichens and minute Algæ. The epiphyte must be carefully distinguished from the parasite, which may also be a dweller on trees. It asks nothing from the tree but a resting-place; it sends no thieving organs deep into the tree's tissues. In a crack or a cleft there collects a little dust and plant debris; seeds light enough to travel on the faint forest breezes fall there; seedlings will thrive if the forest air is moist enough. As the climbing plant makes of the tree a ladder leading to light, so does the epiphyte.

Within our woods there are often clearings; the vegetation which takes possession there will be more luxuriant and richer florally than under the trees. Strong Grasses, Rosebay Willow-herb, Foxgloves, thickets of Bracken are amongst those commonly present.

The margins of the wood show the effects of one-sided illumination. Their undergrowth may be very dense; shrub-growth is mingled with tree seedlings and saplings; Brambles and other scramblers are common; Bindweed, Foxglove, Meadowsweet thrive very well, profiting by the good soil, the semi-shade and the protection from wind.

Next in importance to the illumination is the soil of the forest. Its humus content is usually very high. Three stages in the formation of humus affect vegetation in a very striking way. Sometimes the dead vegetable matter lies comparatively unaltered for a long time as sheets of *litter*; these shut out air from the soil and make life impossible for Earthworms and Bacteria. In the next place, the series of bacterial decomposition changes may be arrested before they are complete (p. 155); the products are known as *raw* or *acid humus*. These may accumulate, as, for instance, in many forests of temperate Europe; they are highly unfavourable to plant life. Finally, where Bacteria and other agents can act freely on the plant matter, the last stages, *mild humus*, are reached, and a rich soil is produced. The unfriendly character of some of the soils accounts for the development on many trees of mycorhizal arrangements (p. 140), for the prevalence of Fungi, and for the presence of flowering parasites and saprophytes.

The zone immediately outside the wood, if it merges into grassland or heath, may show how woodland invades other plant associations. Nearest the wood will be close shrub-growth where, somewhat protected from rabbits and sheep, tree seedlings have managed to grow up into saplings; beyond that would lie scrub of scattered bushes with probably no seedlings. The greatest enemies of young trees are the browsing and gnawing animals—goats being the worst in some places. If it were not for their depredations coupled with man's interference, it is probable that forest would in time regain its place as the main vegetation association in our islands, once so thickly clothed with Pine, Beech and Oak.

A "pure" forest is one in which practically all the trees belong to one species. Over most of the British Isles the factor which determines which tree it shall be is the geological character of the country rock. There are four main types of forest; students having access to them may find some notes useful.

A. On the chalk of the south-east of England, and on the oolitic limestone of the Cotswolds, there are native Beech forests. Beech plantations are found in north-east Scotland. The shade under Beech is so dense that very few plants can endure it. If Beech and Ash saplings start in company as colonisers, the Beech kills the Ash by depriving it of light. Hence Beech woods are likely to be pure. There is no shrub layer, except, at times, Yew, which can stand deep shade. The herbaceous layer is absent or scanty. When the shade is somewhat broken, Wood Sorrel is abundant; when there is still more light, Brambles, Ivy and Holly. Along with these may be found Dog's Mercury, Wood Sanicle, Enchanter's Nightshade, etc. The Beech wood is one of the likeliest habitats in which to find Bird's-nest Orchid and Bird's-nest.

The regeneration and extension of the Beech wood are hindered by the destruction of the nuts by mice, wood-pigeons, squirrels, etc.; by the havoc wrought on tender seedlings by mice, caterpillars, etc., and on young saplings by rabbits and sheep. Only in a "full mast year," that is, when the crop of fruit is heavy, does a fair number of seedlings survive.

B. The heavy clay soils of central and eastern England—including the ancient domain of Sherwood Forest—bear forests of the Pedunculate Oak (*Quercus Robur*). Many of these woods are regularly coppiced, that is, the trees are periodically cut down so that only a few Oaks, the "standards," attain full height; these tower above a coppice of Hazel, small Oak, Ash, Hawthorn—Hazel being far the commonest. In south-east England *Q. Robur* is frequently associated with Hornbeam. Examples of complementary communities (p. 58), mutually exclusive in several senses, are found in this type of wood. In some, competition is lessened by the plants appearing in sequence. The earliest spring plants are Dog's Mercury and Lesser Celandine, so these can exist in spots where summer shade is very deep. Bluebell and Wood Anemone follow these, but also get their flowering over before the Hornbeam expands its leaves. Within the soil, the roots of Dog's Mercury go deeper than those of Lesser Celandine, so these need not starve each other out (Fig. 26).

Other herbaceous plants of this association are Dog Violet, Primrose, Wood Spurge, Wild Strawberry, etc.; many other species are present in the better-lit coppiced woods.

Soil containing much mild humus is highly favourable to Wood Avens, Dog's Mercury and Bluebell. It should be noticed that many forest plants, like Wood Anemone and Bluebell, form colonies which are extended by vegetative propagation.

C. The lighter soils derived from the sandstones and shales of the north-midland and northern areas of England—often of Carboniferous or pre-Carboniferous age—are characterised by woods of the Sessile Oak (*Q. sessiliflora*). The commonest tree associates of this Oak are the Common Elm and Birch; others are Rowan and Holly. The shrub layer varies with the amount of moisture in the soil. Brambles are common; Sloe and Hawthorn are found in the drier situations. The ground vegetation is affected in the same way. Soft-grass, Bracken and Bluebell grow together in the moister soils; there may be plants of the Heath Family in the drier. Complementary associations are characteristic of this wood (p. 58).

D. On the Mountain Limestone of the Pennine region the characteristic woodland is of Ash, with which are associated Sessile Oak, Wych Elm and, at the higher altitudes, Birch. Hawthorn is very distinctive of the higher woods of this area and is one of the most successful advance colonists. The shrub forms also include Juniper, Yew, Dogwood and much Hazel. The ground vegetation varies markedly with the moisture in the soil. (*a*) In wet spots (e.g. by a stream) grow Marsh Marigold, Valerian, Butterbur, Mint, etc. (*b*) Less damp places are covered with sheets of Wood Garlic and Lesser Celandine. (*c*) The driest parts are easily recognised by great beds of Dog's Mercury, under the shade of which, in the early part of the season, flourishes Moschatel, which is a shallow-rooted plant compared with Dog's Mercury. Here, too, there may be sheets of Ground Ivy.

These four woodlands represent our most extensive British woodland associations. To them may be added: the Pine association of Northern Scotland and elsewhere, with which is mixed Birch on the mountain slopes; the Alder and Willow of very wet situations; Yew woods on the south-east chalk and on Yorkshire limestone; Birch mixed with Rowan, which are often dominant in the woods filling the high, upper ends of valleys.

Woods furnish interesting matter for the investigation of questions of seed-carriage, of the struggle of seedlings to establish themselves, of the measure of success with which one plant association invades another. Comparisons should be made amongst the fruits of trees (e.g. the heavy types such as Oak and Beech), which naturally do not travel far from their trees; the types provided with floats, such as Ash, Sycamore and Hornbeam, which begin with a better chance than the heavy fruits of travelling into fresh ground; the soft fruits, such as Hawthorn, which may be distributed by birds. On the nearly barren limestone pavements of the North Pennines the eye catches no vegetation except solitary shrubs of Ash or Hawthorn standing, perhaps, miles from other trees. The seeds may have been carried there by gales or by birds. It is probable that winged fruits do not usually travel very great distances from the trees on which they grew; observations should be made, if possible, to test this.

CHAPTER XXIII

THE WATER-SUPPLY OF THE PLANT

Noiseless and unseen the vapours are drawn up from the oceans by the compelling sun; so also do they mount from the prairie, the wheatfield and the forest. Every plant that lives is withdrawing the waters from the earth and lifting them into the sunlight, giving them up to the air from its million mouths. This intake, this outgiving, and the journey through the plant which lies between them, form the subject of this chapter. We are told that one Sunflower leaf may be breathing vapour from 13,000,000 pores, that one tree pours out every day 100 gallons of moisture, that an acre of Wheat within its season raises through a height of several feet 1000 tons of water. These figures suggest a gigantic task, which must have a gigantic force behind it.

How Water passes into the Plant: Absorption

The process by which water and salts dissolved in it enter a plant consisting of one cell has already been followed (Chap. IX). No new principle and no new mechanism is involved in the most complex of plants: it is merely a question of many cells. Plants absorb water by way of their roots; to this rule there are a few exceptions, such as submerged aquatic plants, which may take it in over their entire surface. The rule is easily verified. Arrange a plant, such as young Wallflower or Broad Bean, in a jar of water, so that its roots only are in the water. Prevent evaporation from the surface of the water in some way, e.g. by a layer of oil on it or by closing the jar with a cork through which the plant passes. Mark the level of the water. It will be found that the water-level falls; water must have been taken up by the plant's roots. Instead of adding the oil-layer, a similar jar of water, without a plant, may be placed alongside as a control. The structures which are the actual doorways of entry are the root-hairs. Root-hairs, by their length, increase greatly the absorbing surface of a root. Their soft, mucilaginous walls come into intimate contact with the soil particles and their water-films.

Study the roots of young seedlings of Wheat, Mustard, etc., mounting the tips in water for microscope examination. Mount some in five per cent solution of common salt. This is strong enough to induce withdrawal of water from the root-hairs, which become flaccid; irrigate the preparation freely with water, and watch the recovery of the root-hairs and other cells.

Reference to Chapter IX. reminds us that the entry of water and salts into a cell is a process of osmosis, which depends upon the presence of two solutions of unequal strength separated by a permeable or a semi-permeable membrane. The cellulose cell-wall of the root-hair is a permeable membrane; the two surfaces of the protoplasmic lining of the wall behave as semi-permeable membranes with respect to certain substances. Within the root-hair is the cell sap, a solution chiefly of sugars and mineral substances, normally of higher concentration than the mineral solutions which lie outside the root in the soil. Thus the conditions seem right for the passage of water from the weak solution outside into the strong solution inside. The *compelling force is osmotic force.* Opposing this round the root-hair are the surface-tension forces holding the water to the soil particles (p. 147), the colloidal forces and the osmotic power of the external water solution itself. If the osmotic force of the cell prevails, the water moves into the root-hair; absorption is accomplished (Fig. 94).

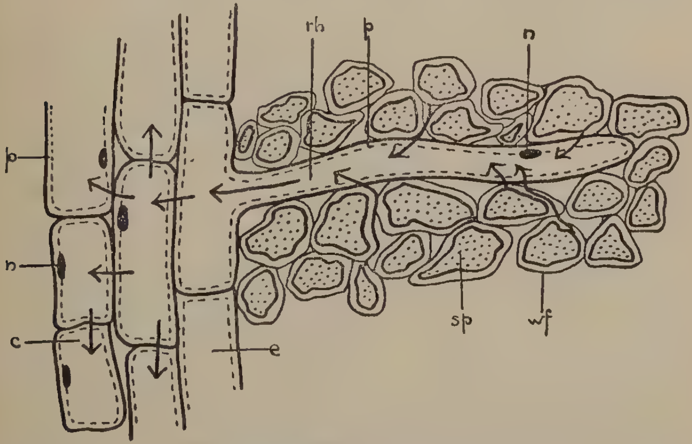


FIG. 94. ABSORPTION BY ROOT-HAIRS

e, cell of epidermis; *c*, cell of cortex; *rh*, root-hair; *p*, cytoplasm; *n*, nucleus; *sp*, soil particle; *wf*, water-film clinging to particle. Arrows show direction in which water may travel.

When soil solutions are highly concentrated, as in salt-marshes or peat-water, absorption of water by the plant is small; there is also risk that internal solutions may become strong enough to be poisonous to the plant. Some trees lose their root-hairs early if they grow in soil containing much raw humus. Their work is done by a web of thread-like filaments belonging to large Fungi; these wrap round the rootlets of the trees. They are in union with the root-cells and pass on to them water and the substances dissolved in it, as well as nitrogen in organic form. This is the mycorhizal association noticed on page 140.

How Water passes out of the Plant: Transpiration

The plant absorbs a very great deal of water; obviously it cannot retain it all; how does it get rid of the surplus? The experiments suggested below are intended to find the answer to this.

(1) A very simple experiment demonstrates the fact that the plant parts with water freely. Pot-plants of London Pride, Primula or young Garden Nasturtium are suitable; be sure that the soil in the plant-pot is thoroughly moist before starting. Use two plants. Cover pot A and its soil with something which will prevent evaporation from them, such as lead foil; stand it on a glass sheet and cover the whole with a bell-jar; guard against leakages as usual. Fit up plant B in the same way, but enclose within the jar a small weighed dish of calcium chloride (Fig. 95). Arrange a control plant-pot, C, in the same way as A, but omit the plant. Watch how the inside of the bell-jar in A becomes bedewed with moisture. At a stage when this has become very plentiful, re-weigh the dish of calcium chloride in B; it will be found to have gained weight. This substance is known to absorb water readily. In jar B moisture did not gather on the glass; it had joined the calcium chloride. In C no moisture appears on the glass. The inference to be drawn from this experiment is that the shoot of a plant gives off water. The water leaves the plant as vapour; the process is called *transpiration*.

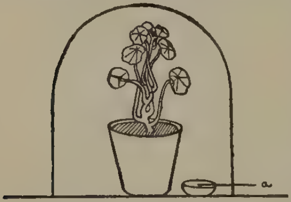


Fig. 95. Experiment: Loss of Water by Transpiration

a, dish of calcium chloride.

(2) Compare transpiration and absorption. Fix a plant with good roots, by means of a split cork, in a jar quite full of water. The jar communicates near the bottom with a narrow vertical tube, graduated in cubic centimetres, which also contains water and which is closed at the top. Weigh the whole apparatus and the plant at the beginning of the experiment. Place it in favourable light and warmth. The level of the water in the tube will fall hour by hour; this must be recorded periodically. The

water lost from the tube is passing into the jar and thence into the plant. Re-weigh after some centimetres have been lost. There is a loss of weight, which shows that the water taken in has not all been stored in the plant. Note the number of centimetres lost from the burette; they correspond to the same number of grammes' weight of water. Do you find that this loss is exactly the same as the difference between the two weighings? If it is, then all the water absorbed by the plant has probably been given off by the plant. In one school experiment, the weight of water absorbed was 4·8 grm.; the weight lost was 4·7 grm.: that is, about two per cent was apparently retained by the plant. This result covers errors which, seeing that the plant is small and the time involved is short, may in this case be neglected. It must not, however, be forgotten that the plant is adding to its weight by assimilation of carbon dioxide from the air, and is losing by respiration. Watch must always be kept for such possible sources of error.

(3) By the use of the *potometer*, transpiration can be measured more accurately than in (2), and conditions varied. A jar, *a* (Fig. 96), is fitted with a three-holed india-rubber cork. Into one hole is fitted the branch of a plant, such as Laurel; into the second, the tube of a thistle funnel provided with a stopcock; into the third, the end of a capillary tube, *b*. The last is bent twice at right angles; one short arm ends at the lower surface of the cork; the other dips into a dish of water, *c*. A graduated scale is attached to the tube.

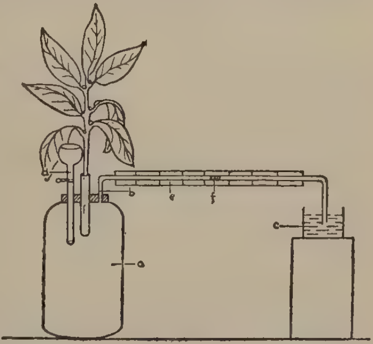


FIG. 96. EXPERIMENT: POTOMETER

Prepare the branch. When removing it from the plant bend it so as to make the cut under water. (For reason, see experiment p. 270.) It should then stand in water for several hours before being fixed in the cork; cut off a short piece of the stem before fixing it. Fill jar A to overflowing with water freed from air by boiling. Fix all parts of the apparatus in position, the capillary tube and the funnel tube filled with water, the cork joints perfectly airtight. As the plant parts with water from its leaves, it takes up water from jar A; water moves into A from the capillary tube, which draws upon C. The precautions taken with the branch ensure that its water system is normally filled when the experiment begins, so that the rate of intake will tend to be steady if the external conditions are not altered. It remains to make the movement of the water visible. By lifting the end of the tube for a moment out of the water in C, a little air enters it and is pushed along as a bubble when the tube is replaced in the water. It is easy then, by using the scale, to find the rate at which the bubble and, of course, the water, travel towards the branch. This rate is also (with corrections as above) the rate of transpiration. When the bubble gets near the end of the tube, the stopcock may be opened and a very little water allowed to enter A; this drives the air-bubble back towards C, and a fresh start may be made. The average of the results from a series of experiments should be taken. By varying the conditions it can be shown:

(*a*) that transpiration is more vigorous in good light than in shade;
(*b*) that it is increased by exposure to currents of air;
(*c*) that it is greater in a dry atmosphere than in moist;
(*d*) that it falls when leaves are removed from the shoot and when certain leaf-surfaces are coated with vaseline;
(*e*) that a deciduous shoot loses water more quickly than an evergreen shoot.

(4) Transpiration from one leaf may be shown. Select a long-stalked leaf from a pot-plant; leave it on the plant. Enclose it in a wide-mouthed bottle by fixation through a split rubber stopper; see that junctions are perfectly sealed. Give the bottle support. The inside of the bottle soon becomes clouded with moisture which must have come from the leaf.

(5) Are the exits from the leaf confined to any particular part of its surface? Experiment with fairly large leaves removed from a plant. Seal up the end of the petiole with wax. Dip the leaf into warm water and hold it there. Little air-bubbles will show on those parts of the surface where there are openings to the interior. The bubbles have emerged from the pores owing to the expansion of the warmed air within the leaf-tissue. Confirmation of the distribution of the pores (stomata) may be got by stripping the epidermis from similar leaves and making microscope examination of it.

(6) Test the action of the stomata. Choose (*a*) two similar leaves of Laurel, and (*b*) three similar leaves of Broad Bean or Sunflower. Stop up the cut ends of the petiole with wax. In (*a*) smear with vaseline the upper surface of one leaf and the under surface of the other. Weigh the leaves and suspend them in a place at ordinary temperature. Watch the rate of withering and weigh the leaves when that has advanced pretty well. The leaf vaselined on the upper surface loses water more quickly than the other; their stomata will be found only on the under side. (*b*) Vaseline one leaf on the upper, one on the lower, and the third on both surfaces. Deal with them as in (*a*). There is very little difference in the behaviour of the two leaves coated on one side only; the leaf coated on both sides remains fresh much longer than they do. In these leaves stomata occur on both surfaces.

(7) More delicate tests on stomata may be carried out with cobalt paper. This is prepared by dipping filter-paper into cobalt chloride and drying it. Test the dry paper by breathing on it; the moisture in the breath changes it from blue to pink; with

continued exposure it becomes colourless. Ascertain by microscope examination the distribution of stomata on a few leaves. Arrange pairs of each kind on a sheet of dry blotting-paper or well-dried glass, one with the upper, one with the lower surface turned upwards. Place freshly dried cobalt-paper over each. Then cover the whole with a sheet of well-dried glass to shut out atmospheric moisture. It will be found that the pink reaction to moisture, followed by loss of colour, coincides with the distribution of stomata as seen in the microscope preparations.

(8) It must be ascertained if any water vapour passes out through the walls of the epidermal cells. The appearance of evergreen leaves suggests that they are specially protected against such a loss. Take a leaf of Ivy and a leaf of Wallflower, in both of which the stomata are confined to the under side. Cover the stomatal areas with vaseline; if transpiration goes on it must be through the general cuticles of the upper surfaces. In time, both leaves dry up, but the Wallflower leaf dries more quickly than that of Ivy. Cuticular transpiration does occur, but the thick cuticle of Ivy reduces it to a minimum. Except in very young leaves, cuticular transpiration is of little importance.

(9) If stomata are to act properly they must not be covered by water-films. Immunity is secured sometimes by the waxy nature of the leaf-surface, sometimes by its being hairy. The wax gives the " bloom " to a leaf. Take such leaves as Broad Bean, Carnation or Garden Nasturtium. Dip them into cold water; a film of air between the water and the leaf-surface shows as a silvery sheet. Remove the leaves; notice that water does not adhere to them. Take special note of the appearance of leaves in the garden during rainfall. Rub off the bloom from a leaf and place it in water; it is wetted. Bloom serves a second purpose; it acts in the same way as cutin, preventing the passage of water vapour. Cuticular transpiration should thus be increased if bloom is removed from a leaf. Test this as in experiment (6).

(10) Normally the plant gives off its surplus water in the form of vapour. In certain circumstances liquid water may be forced out. Drops may be seen sometimes in the early morning on the tips of young Wheat blades and at the ends of the main veins in young leaves of Coltsfoot (p. 165) and Garden Nasturtium. Their formation may be encouraged by covering one of these plants with a bell-jar and supplying it with plenty of water. In such cases, absorption of water during the night has been more than enough to restore turgidity weakened by transpiration on the previous day. At night and in the early morning, especially if the atmosphere is humid, transpiration will be slow. Hence the pressure is relieved by the direct escape of water from the ends of the veins. It comes to the surface through special pores, or *water stomata*, placed in line with the vein-endings. They possess guard-cells, but these guard-cells are always open. These pores are also called *hydathodes*. In some plants (e.g. Saxifrages), glandular tissue is developed in these spots; the gland is a small mass of secreting cells between the tip of the vein and the stoma. They

separate out calcium carbonate, etc., from the cell sap (*chalk glands*). This may gather as an incrustation round the stoma, when the water evaporates (Fig. 56).

How Water Travels within the Plant: Conduction

Water enters by the roots and passes out by the leaves. By what channels does it travel from one to the other? We must know whether it makes use of all the tissues of root and shoot, or which of them function specially as water-pipes.

To get an outline of the answer we carry out a simple experiment based on the fact that water may carry with it into the plant substances in solution. Water coloured with eosin or red ink serves very well. A varied assortment of plant specimens may be examined—a leaf such as Primrose, Sunflower or Pelargonium; a herbaceous shoot, e.g. Garden Nasturtium, Vegetable Marrow; a woody twig, e.g. Sycamore, Lime; a one-year-old Wallflower shoot; a whole plant, e.g. Groundsel, Wheat seedling, Broad Bean seedling; a shoot with white flowers, e.g. White Bindweed; a flower with peduncle, e.g. Narcissus; a large bud like Brussels Sprout.

The specimen is left for a time in a vessel containing the coloured liquid; sometimes the colour spreads quickly, sometimes it is necessary to wait a day or two for results. The Brussels Sprout shows very distinctly the isolated water channels, and also their continuity from stem to leaf (Fig. 69). After standing in the solution for some time, the bud should be cut transversely and longitudinally and examined with a lens. The transverse section shows the red colour located in the inner part of each one of a ring of wedge-shaped areas; the same section through the surrounding leaves shows in each leaf three similarly coloured areas. These areas are vascular bundles (p. 194), and the stained part is the xylem. Thin sections may be made and put under the microscope; it is the vessels in the xylem which contain the water. In the longitudinal section two red lines run up to the apex enclosing a central uncoloured core; from these, red branches enter the leaves to form parts of veins. When roots are included in the plant used in the experiment, only part of them should be immersed; as water soaks into those roots lying within it, all their tissues may become tinted. The root standing above the liquid will have in the centre a strand of reddened tissue, that which is conducting water to the stem. The region where the vascular system of the root is transformed into that of the stem (p. 194) should be looked for. To speed up the root-test, the tips of the older roots may be removed.

The water routes in Wheat seedling (Monocotyledon) may be compared with those in Broad Bean seedling (Dicotyledon). Garden Nasturtium responds quickly, and is soon coloured throughout its chief leaf-veins. The delicate pink veins which spread a blush over white flowers are very charming.

By combining results from several plants it is made clear that water travels along an uninterrupted system of communicating strands—the xylem or wood—from the finest roots to the finest veins of leaf and flower.

Different treatment may be given to a small branch left in connection with a shrub. Remove from it a ring of tissue about an inch broad, cutting away everything down to the wood; cover up the wound. It may be left for weeks. It will be found that the leaves above the cut are as well supplied with water as before; bast, cambium, cortex, epidermis had played no part of importance in conducting water upwards. Pith, too, may be ruled out as a conducting tract; it is often destroyed, with no ill effects.

THE FORCES ACTING ON THE WATER CURRENT

Why *does* water move upwards in a plant? Is it driven up by pressure from behind, or is it sucked up, or is there still another explanation? These are extraordinarily difficult questions to answer, and they are still matters of acute discussion. Our part is to examine some of the phenomena relating to them.

The Driving Force acting in the Root. Take a pot-plant in vigorous condition—a Fuchsia is one of the best, and Vegetable Marrow is good. Prepare it by watering it well, and keeping it in the shade until needed. Cut it down to within an inch or two of the soil (best done under water). Slip over the stump a short length of rubber tube and into this insert a long, capillary, glass tube. Bind these securely in place with wire. The tube should be three feet long or so, and must be clamped to a support. Put a little water into it, and on the top of that a little oil to prevent evaporation. Keep the pot-soil moist and warm. Very soon the water column in the tube lengthens; water is being forced out of the plant stump. With Fuchsia, the column may reach 250 cm.; a tube long enough to take all the increase shows that at a certain level the column remains stationary. The rise of the water is said to be due to *root pressure.* At the point when it rises no farther, the force of the upward pressure is just balanced by the weight of the column of water. Root pressure varies very greatly amongst plants. It manifests itself chiefly in spring; it may also be greater by night than by day. Knowing these facts, the gardener generally does the pruning of his fruit-trees in autumn when root pressure is at its lowest and there is less risk from what he calls the "bleeding" of the plant. In plants where the pressure is strong, a short column of mercury will be found more convenient than a long one of water. For the straight tube is substituted a bent tube (Fig. 97) attached to the stump as before. It must be manipulated till the mercury stands at the same level in both arms, water filling (*a*) and part of (*b*). The long arm should be at least two feet long. Root pressure acts through (*a*) and drives the mercury up the long tube. The difference between the levels of the mercury in the two arms, when stability is reached, indicates the amount of root pressure. It may be expressed in terms of atmospheric pressure. The length of a column of mercury which will be supported by the pressure of one atmosphere is known to be 76 cm. If the difference in level is 38 cm., then root pressure is equal to half an atmosphere. At its most vigorous, Fuchsia gives a pressure of a quarter of an atmosphere, 19 cm. of mercury or 250 cm. of water. The vine shows great spring pressure. It will raise water more than ten metres, that is, more than one atmosphere.

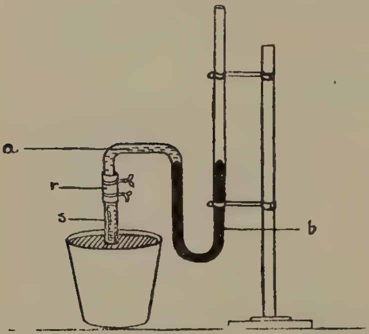
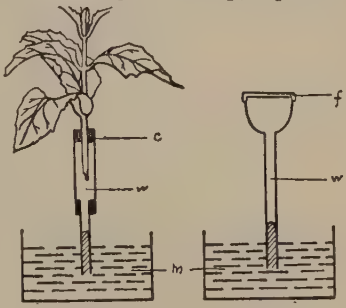


Fig. 97. Experiment: Root Pressure
a, water; *b*, mercury; *s*, stump of Fuchsia; *r*, rubber tubing.

The nature of root pressure will be discussed on page 268.

The Lifting Force acting in the Leaf. There is a force doing "lifting" work in every transpiring tree. We remember that transpiration is not identical with evaporation, but we also remember that evaporation—the changing of liquid into vapour—is essentially bound up with it. We remember also that evaporation is the work of a force, namely, the energy of the sun's rays. Can it possibly be this force which sets going the long line of minute movements which result in water being *drawn* from the root to the leaf? We have seen that there is a really unbroken, though seemingly tortuous, trackway for the water. We have also seen that there is a force at work *pushing* water through the roots and some way up the stem. The effects of these two forces, pulling and pushing, must be estimated.

Let us demonstrate the power of the force which carries on evaporation independently of any living tissues. A thistle funnel (*f*) is filled with boiled water (*w*), and set up, dipping into a dish of mercury (*m*) (Fig. 98). The funnel mouth is covered with parchment or with plaster of Paris. Left in a moderately warm place, the water in the tube grows less owing to evaporation through the porous membrane closing the funnel; the mercury in the tube rises steadily up to a point. Directly air gets into the funnel, as it does by back action through the membrane, the upward movement of the mercury is checked. The air, collecting at the top, separates the surface of the water from the membrane. What has been happening in the funnel? You can take hold of a solid rod by one end and lift it upwards; you can draw up a string with a weight at the end of it; but is it possible to draw up a rod-shaped column of water? That sounds impossible. Given right conditions, it is possible. The force of cohesion—that holding the molecules together—is very strong in solids; it is less strong, but it exists, in liquids. This force expresses the *tensile strength* of a water column. If a lifting force is applied to one end of such a column, the column will rise, provided its tensile strength is great enough to hold it together. In our experiment the lifting force is the force inducing evaporation in the water passing through the plaster of Paris. It exerts a sucking action, drawing more water upwards. There must be no break in the water column. It is when the continuity of the column in the funnel is broken by an air-bubble that it ceases to rise.



(2) (1)

FIG. 98. EXPERIMENTS: FORCE OF TRANSPIRATION

(1) Evaporation through porous partition. (2) Transpiration from leaves.

Place alongside this purely physical experiment its counterpart in the living plant. Substitute a leafy branch for the thistle funnel and its membrane. Fix it into a tube by a perfectly fitting cork (*c*), fill the tube with water and set its lower end in a dish of mercury (Fig. 98). The mercury behaves as in the other case. It may rise much beyond the height of a column supported by the atmosphere. Evaporation is taking water from the cells round the spaces within the leaf; this pull may be transferred to the water vessels of the leaf and through them to the stem; this again to the water in the glass tube. This is a long column, or series of connected columns, and the doubtful part of the matter is whether or not there are any breaks in it. If not, then we have here a possible explanation of the ascent of water in plants. Further reference will be made to it.

How Stomata control Transpiration

Let us recapitulate one or two points concerning the green leaf. The epidermal cells have walls so altered that it is only with much difficulty that either water vapour or carbon dioxide can pass through them. In this way the leaf is saved from desiccation. But the leaf must have carbon dioxide, and provision for its entry is made through microscopic openings between the epidermal cells. Through these openings water vapour also can diffuse. Further, it has been ascertained by experiment that gases will diffuse as readily through a membrane pierced with holes as from an uncovered surface, provided that the holes are small enough and numerous enough. Diffusion is greater through a large number of small holes than through a small number of large holes, even when the total areas are equal. At first sight, therefore, it looks as if the plant gained nothing in safety by adopting a perforated waterproofed skin. The gain lies in the fact that the openings can be closed; *the passage of gases can be regulated*. This is effected through the changes in shape of the two guard-cells which surround the opening (p. 199). The soft leaf-tissue consists of thin-walled cells which, when the leaf is active, are turgid with cell sap. Through the whole tissue ramify intercellular spaces; into these evaporation from the walls of the cells is continually going on, so that the air in them is saturated with water vapour. This saturated air diffuses through the

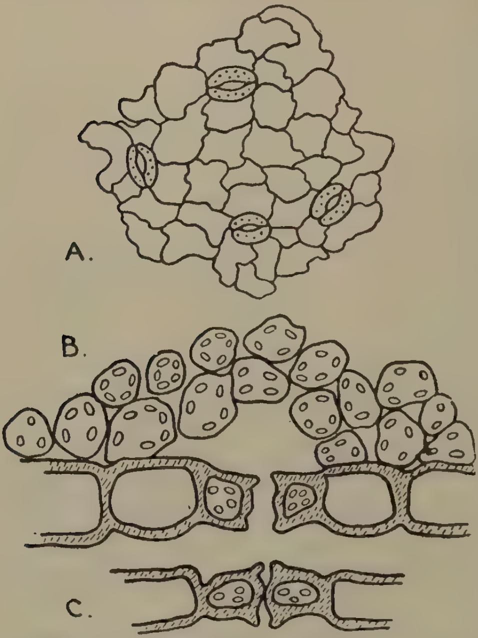


Fig. 99. Stomata

(A) Stomata from under surface of young Coltsfoot leaf: surface view; (B) Transverse view: pore open; (C) Transverse view: pore closed.

stomata into the outer air, *when the stomata are open.* The stomatal pore is fully open when the stomatal guard-cells are fully turgid. This is the opposite of what one would expect. It is explained by the unequal thickness of the walls of the cells. They are, speaking generally, thinner and more readily extensible in the parts other than those bounding the opening. When the pressure within the cell rises, the thin areas bulge and draw the firmer areas apart from each other. When pressure falls, the latter fall back into contact as part of the collapsing movement. The turgidity of the cells depends on two factors. One is a high osmotic pressure maintained by the formation within them of sugar and other osmotic substances, which is possible in light because chlorophyll is present in the cells. The other is that sufficient water should be available to meet the call of the osmotic cells (Fig. 99).

The automatic response to the plant's requirements given by the stomata seems satisfactory. When the leaf as a whole is turgid, and its turgidity is being kept up steadily by supplies from the roots, it is desirable that evaporation from the cells into the air-spaces, and thence to the air outside, should be rapid. The pores should then be open. They are open, given other conditions are right. The guard-cells share in the general turgidity and their distended condition leaves the pores open. If the water conditions are reversed, transpiration may be harmful to the plant. That is a time when the guard-cells will be flaccid, as the others are, and will fall together, closing the pores.

External as well as internal factors are influential. When the temperature of the atmosphere is high, more water is required to saturate it; evaporation may then be so rapid that the transpiration current cannot supply water to meet it and to maintain turgidity in the leaf as well. The leaf wilts. Examination of the epidermis of a leaf in this condition shows that the stomata have closed; as soon as this happened the loss of water would be checked. The closure would, of course, be caused by the guard-cells losing moisture either to the air or to the other cells. Such plants will subsequently revive when shaded and watered; a few, like Royal Fern, are killed because their stomata have no power of closure.

A dry atmosphere hastens transpiration; plants do not wilt in very humid weather even if the weather is hot; the air is too near saturation point to take up much more moisture. When currents of air play on a leaf-surface they remove the saturated air as it issues from the pore, and diffusion outwards is kept up at a high rate.

Stomata usually close in darkness. One reason for this must be that in the absence of light the sugar-making activity of the guard-cells ceases, and the sugar already made is removed to other cells or is changed into starch. This means lowering of the osmotic pressure in these cells and a movement of water from them into adjacent cells. They therefore partially collapse and close the pore. It is said that they often close just a little before sunset and reopen a little before sunrise.

Everything that has just been written gives the idea that the stomata constitute a most efficient system of valves, controlling automatically the loss of water from the plant, so that withering is prevented. There is, however, some doubt about the efficiency, as well as more doubt about our understanding the process quite correctly. The part which light plays, for instance, is more complicated than is shown in the statements made above.

SUMMARY

Let us now try to fit all the information we have obtained from experiments and from plant structure into one continued story. We begin with the root-hair. Water from outside enters this in obedience to osmotic pressure. Its entry increases the turgidity of the root-hair cell. Cortical cells in contact with this cell are passing water inwards, and will be ready to take water from the root-hair. Water will pass from cell to cell of the cortex by osmosis. It is not to be understood that it is by progress upwards in this fashion, through the cortex, that the main water current reaches the top of the plant. For one reason, it would be altogether too slow. But water does cross the cortex, make its way through the unthickened walls of the endodermis, and arrive at the xylem vessels. Entrance to these can be made through the thin places in the walls. Then the water is in the position of the water in the thistle funnel under the plaster of Paris. There are many tubes here, however, placed end to end; their end, separating walls must be, apparently, as porous as the covering of our thistle funnel if the column of water is to move up in the same way. *Somehow* (we will leave it at that for the present) the water does reach the most distant points in the plant, makes its way to every plant cell which has need of it. It reaches, for instance, the fine veins lying amongst the thin-walled cells of the spongy leaf-tissue (p. 199). The xylem elements in these veins are very delicate; water can leave them easily. It is urged to do so: it is again within the immediate influence of osmotic forces. The parenchyma cells touching the xylem exert an osmotic suction on the water in the vessels; they themselves are being drained by cells alongside them, and these by the cells which line the intercellular passages opening outwards through stomata. What happens now? These last cells are affected by the purely physical process of evaporation. This, possibly modified by the living protoplasmic lining of the cell walls, deprives the cell of water in the form of vapour. The saturated air diffuses outwards; transpiration is accomplished. Its direct effect is to induce concentration of the solution within the outermost cells, to increase their osmotic pressure. In this way it initiates the chain of events, mainly osmotic, which we have just traced in the reverse direction (Fig. 100).

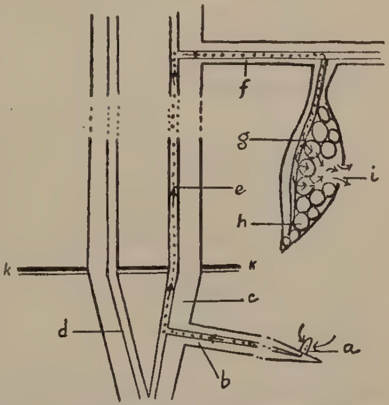


Fig. 100. Path of Water through Plant
Proportions not correct.

a, root-hair; *b*, rootlet; *c*, cortex; *d*, xylem of main root; *e*, xylem of stem; *f*, branch; *g*, vein of leaf; *h*, cortical cell of leaf; *i*, stoma; *k*, ground level.

Is there, in the "driving" osmotic force shown as root pressure, or in the "pulling" osmotic force shown in transpiration suction, or in the two combined, power great enough to lift water to the top of the highest tree along those paths which we know it follows? No scientist, at the present day, would dare to say that there certainly is. Root pressure is not known to raise water higher than eighty feet in a tree, whilst trees may reach hundreds of feet in height. Another great objection to attaching much value to it as a water-raising agent is that in many plants it manifests itself only in the springtime. The greatest difficulty connected with the transpiration "pull" lies in the character of the water column in the vessels. The osmotic force exerted through the chain of leaf-cells on this column may reach thirty atmospheres, which would seem to be ample to lift the longest columns. But rarely are the xylem vessels filled with a continuous column of water. Large air-bubbles may be present; sometimes, indeed, the vessels are empty but for a film of water along the walls. Given that this film is not interrupted, there is a series of water cylinders connected through the porous partitions. The aggregate of these cylinders may behave like a water column. The nature of the transverse walls in this vascular system will be a critical factor in regard to the columns. Even when a good deal of air is present it may not completely block the passage for water cylinders. It is a point to be noted that the air in the tubes is often much below the pressure of the external atmosphere; this was the reason that certain precautions were taken in experiments (p. 259). The truth of this may be proved by taking a plant which has been transpiring freely in the sunshine, and, bending a branch of it under water coloured with eosin, cut it off and leave it in the solution. In a few minutes the red colour will probably be found to have mounted several inches—driven by the pressure of the atmosphere, which has been greater than that within the vessels of the branch.

There is a third force which might be supposed to act within the xylem vessels, namely, capillary force (p. 148). It has, however, been proved that this force could raise water only a few inches in wood-cells—perhaps a few feet if conditions were extremely favourable. Other theories have been advanced to explain the ascent of water in plants, but the discussion of them is out of place here.

Plants absorb great quantities of water and great quantities leave the plants—far more than is needed to keep the cells moist. Is there a reason for the seemingly over-generous character of this stream? Whilst we need not regard them as reasons, we may recognise two very beneficial results which it brings to the plant. First, the work which the leaf does in manufacturing material for renewing and extending plant substance requires liberal supplies of mineral salts. The solutions of these salts taken in by roots are very dilute, therefore it is necessary to bring them in large amount to the leaf where the salts are left behind when the water evaporates. Second, the sun's rays falling on stones may raise their temperature pretty high, whilst the plants growing alongside are quite cool to the touch. Heat in great amount is used up in carrying on the evaporation of the water in the leaf; that heat is lost as far as raising the temperature of the leaf is concerned; thus the plant is protected from excess of sunshine. Further, a moist leaf is less liable to extremes of temperature, just because water heats less rapidly and cools less rapidly than dry substances do.

Some of the water absorbed is retained within the plant. Every living cell needs water; it must be at least reasonably turgid. Before the mechanical strengthening tissues of a plant are developed, its parts are kept in position by the strongly turgid cells; when these become flabby the young plant wilts and falls over. It is the osmotic force of its turgid cells which gives the seedling its power to remove obstacles from its way. Apart from the movement of water in the xylem vessels, it can move throughout the tissues by osmosis from cell to cell. During certain periods of the year, water may remain in the xylem vessels as in reservoirs. In some of the Horsetails, the water collects in the large cavities left by the disappearance of pith as if they were tanks.

The water-stream through the xylem carries with it mineral salts in solution.

TRANSLOCATION OF ELABORATED FOOD

The substances elaborated by photosynthetic processes in the leaf are required for making or renewing tissue in many parts of the plant. They have to be taken to these places, and they have often to be stored up until they are wanted. *Translocation* is the term used in speaking of their transport. It is not quite certain how it is accomplished. It is practically certain that everything moved must be soluble and diffusible. It would be possible for it to pass from cell to cell, through the cortex, for example; that would be a slow way. There is a good deal of proof that much of it travels down the phloem vessels, the sieve-tubes; these contain sugar and nitrogenous substances which are often massed close to the sieve-plates (Fig. 72). From these tubes they pass out at various levels, and may be stored up in the living cells which form part of both wood and bast bundles, as well as in the cells of the cortex, pith and—very abundantly—the medullary rays. A substance which travels as sugar will, when it enters the storage cell, often be changed into starch by the agency of enzymes. Other storage substances are oil, sugar and inulin. When the stored material is wanted for use it is changed back into a form in which it can travel as before. In spring, at least, sugars may travel by another route. They are found, often in large quantities, in the water current in the xylem vessels; this is well known about the sap of the Canadian Maple-trees.

It must not be overlooked that gases also are continually journeying throughout the plant. They diffuse along the network of intercellular spaces. Oxygen is taken into the plant and sent through it; carbon dioxide is collected up from the tissues and sent out. This is a necessity, for every living cell must respire. Further, the oxygen and carbon dioxide involved in the photosynthetic process circulate amongst the cells.

CHAPTER XXIV

ECOLOGY

This chapter will summarise some of the ecological information contained in previous pages, and will also give outlines of some plant communities not yet touched upon.

Ecology is that aspect of botany which treats of plants as they grow in communities in their natural homes. Various specialists have worked out schemes of classification and nomenclature; a very few of the best established are included here. The term *community* is the most general, the widest in its significance; it can be applied to any assemblage of plants, of any grade, which has an individuality which can be recognised—that is, which can be regarded as a *unit of vegetation*. For instance, the vegetation rounded off as the entity called a Beech wood is a community; so is an open glade within any wood; so is the tiny company of plants settled round the pool within the glade. The botanists grade plant communities downwards from

(*a*) the great *Plant Formations*,[1] e.g. tropical grassland, down to
(*b*) the *Plant Association*, to
(*c*) the *Plant Consociation*, and to
(*d*) the *Plant Society*. These are the most important terms used to describe units of vegetation.

The plant *association* is generally accepted as the *standard unit* from which to work. It is illustrated in the ash-wood, the fen, and the salt-marsh associations.

Within a heath association it may be possible to distinguish an area dominated by a single species, i.e. purple Heather or Ling. This smaller community would be an example of a *consociation*.

A plant *society* is a still smaller, more local assemblage of plants having distinct characters, and placed within one of the higher communities. For instance, there may be on the Ling heath a peaty pool, the plants on the margin of which would be characteristic enough to form a society.

Vegetation which has not been altered by man is *natural* vegetation, e.g. virgin tropical forest. Vegetation altered by man is

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[1] This term is used with somewhat varying meaning by the workers in different countries.

semi-natural, e.g. a burnt moor. Vegetation initiated and maintained by man is *cultivated* vegetation, e.g. a cornfield.

Any plant which, by reason of the number of its individuals or of its size, determines what shall be the plants associated with it in a community is called the *dominant* plant of that community, e.g. Grass in a pasture-field, the Oak in an Oak wood. There may be *co-dominants* of equal rank or a second of somewhat less prominence, a *sub-dominant*. The other plants are *subordinates*.

A community may be at a stage when it is changing; in the course of some years new species may enter it, old species may disappear from it, or the relative importance of its members may alter. Such would be an *open community*. It may be one phase of several leading to a *closed community*. In the latter there is comparative stability, and in general not much chance for new entrants to get established. The closed community is the highest type which any particular habitat, its whole range of factors being considered, is capable of maintaining. It is the *climax* community for that habitat.

The term *habitat* covers all the factors operating within the environment of a plant community which affect the character of the community. It is also used in the narrower sense of the actual place in which the plants grow. The factors are grouped as *climatic*, *physiographic*, *edaphic* and *biotic*. For the most part they have already been treated in detail as occasion arose, and reference should be made to the pages concerned. A résumé will suffice here.

(1) **Climatic Factors** include: the amount and seasonal distribution of rainfall; the temperature of the air and of the soil; diurnal and annual variation in temperature; humidity of the atmosphere as determining its evaporating power; the amount and quality of light at all seasons of the year; the strength of winds.

(2) **Physiographic Factors.** A hill may afford protection from cold or drying winds; may have a wet side to the windward and a dry to the leeward; may receive far more sunshine on a southern than on a northern slope; may be high enough to show the effects of altitude on growth. The deep, narrow valley bottom receives the cold down-drainage of night air, and may have a more trying climate than the slopes above it. Steep slopes usually have shallow soils, may be too steep for vegetation to keep a hold. Also under this head come changes in natural features, e.g. denudation by rivers, alluvial land formed by rivers, new land formed along a sea-coast, etc.

(3) **Edaphic or Soil Factors.** These include: the depth of the soil; its chemical composition; the soil-texture; the relative proportions of mineral and vegetable matter; the water conditions within the soil; the rate at which the soil is augmented by decomposition of the underlying rock or by material transported from a distance.

(4) **Biotic Factors** comprise:

(*a*) The activities of living creatures within the soil.

(*b*) The destruction of plants by animals which feed on them, especially on seedlings and flower-buds. The selective taste shown by animals in their feeding gives an advantage to certain plants in a community.

(*c*) The dispersal of seeds and fruits by animals which eat them or by animals to whose bodies they adhere.

(*d*) The doings of man in rearing animals, in cultivating the soil, in forestry, in draining and irrigating, in reclaiming waste land, etc.

MOORLAND

The moor, using the term in the strictly correct sense of peat moor, is a habitat of extremely pronounced character.

Our moors are fairly elevated and they are treeless, hence they are exposed to trying insolation and to the full effect of winds; they are, for these reasons, situations where excessive transpiration is likely to occur. On the other hand, they come into existence only in places where the rainfall is considerable and where soil drainage is defective, e.g. where the ground is coated with glacial clay. This at first sight seems to counterbalance the desiccation factors. But the critical factor in the moor habitat is its soil, which is of deep peat. This peat is the partially decomposed remains of plants, compressed into a black or brown mass. A peat soil is extremely acid in its reaction. It contains only a low percentage of mineral matter. The reasons why peat is formed in certain situations are still obscure. There must be abundant moisture, retained for a long time in the soil. Most of the peat in the world is found in cold climates, and it has been thought that low temperatures, hindering bacterial action, were the main cause; but recently, extensive peat deposits have been found in sub-tropical

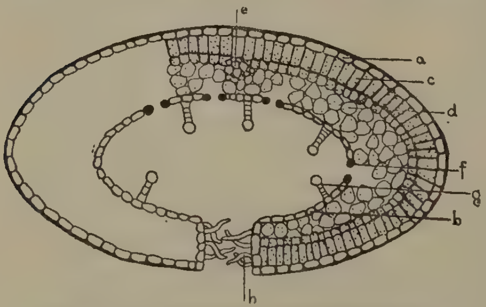

FIG. 101. CROWBERRY (*Empetrum nigrum*)
Section of xerophytic leaf.

a, epidermis of upper surface; *b*, epidermis of under surface; *c*, palisade parenchyma; *d*, spongy parenchyma; *e*, vascular bundle; *f*, guard-cell of stoma; *g*, club-shaped multicellular hairs; *h*, unicellular hairs closing entrance to cavity.

regions. Other factors which must operate are the absence of carbonate of lime, which is essential to some bacterial processes, and the absence of air, which is consequent upon the soil's being continually water-soaked. A view which has been widely accepted is that bacterial work in decomposition is checked at a certain stage by the accumulation (due to lack of drainage) of certain products of bacterial activity which are poisonous to the organisms.

The acidity of the soil solution makes the peat soil a *physiologically*

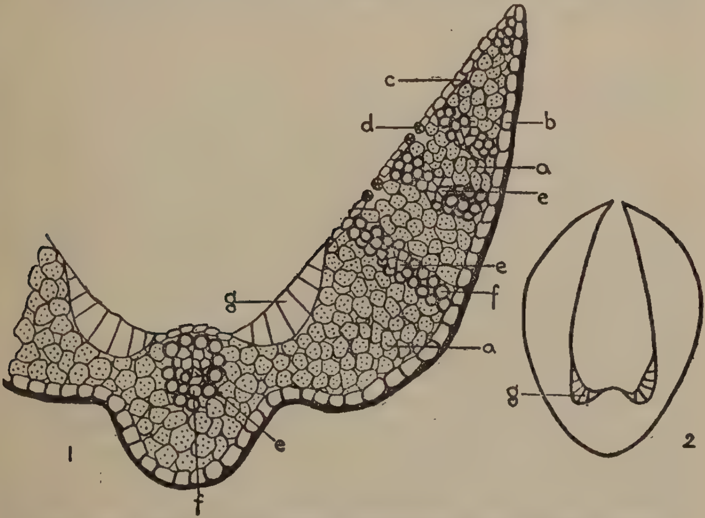

FIG. 102. SECTION OF LEAF OF BLUE MOORGRASS (*Sesleria cœrulea*)
(1) Open leaf-blade; (2) Closed.

a, assimilating tissue; *b*, lower epidermis, outer walls of cells very thick; *c*, epidermis of upper surface, thin-walled cells; *d*, guard-cell of stoma; *e*, vascular bundle; *f*, thick-walled tissue; *g*, hinge-tissue.

dry one. A plant cannot, without danger to itself, make use of more than a small amount of such a solution. Hence the plants of the moor, in the midst of seeming plenty—liable to lose much water and unable to replace accordingly—can exist only if they are specially fitted to resist drought. They nearly all belong to the class of *xerophytes*, or plants adapted to drought conditions. They are protected against over-transpiration in the following ways: the leaf-surface may be smaller (e.g. Heather); the epidermis may be thick and the leaf-surface hard (e.g. Ling); stomata may be hidden away on the under surface of the leaf and may open into chambers formed by the inrolling of the leaf-edges (e.g. Crowberry) (Fig. 101); many moorland Grasses have leaves folded in such a way that the stomatal openings are enclosed (Fig. 102). The low habit of growth of most moor plants lessens the risk from wind.

The moor bears various plant associations, of which the *Heather Moor Association* is, in this country, the most extensive and the most beautiful. It is common on the eastern lower slopes of the Pennines. For sporting reasons, the vegetation is checked by periodical burning; the regeneration after this is very interesting. The dominant plant of the heather moor is the common Ling (*Calluna vulgaris*); associated with it may be the narrow-leaved Heath, Crowberry, Cowberry, various moor Grasses, Lichens (on the ground), etc. Another type is the *Bilberry Moor Association*, dominated by *Vaccinium Myrtillus*, with which may mingle Cowberry and various Heaths. Both these associations belong to comparatively dry moorland. The Association of *Scirpus cæspitosus* (Deer's-grass) belongs to wet and deep peat; it is widespread in the north-west Highlands of Scotland. Those Pennine areas where very deep peat is saturated with water at all times, and where peat is still accumulating, are covered by the monotonous *Cotton-grass Association*; the local name for it is a "moss." There is a still wetter type of moor—the *Sphagnum* moor—with few plants besides bog-mosses; it is a veritable sponge.

If the student has the opportunity he should examine sections cut through deep peat. The stratification lays bare the succession of vegetation belonging to many centuries. Peat beds between thirty and forty feet thick occur in the north of Scotland; their record goes back nearly to the Ice Age; one forest seems to have succeeded another, after intervals, in regions now treeless; the trees included Birch, Willow, Pine and Alder.

At the present time the peat moors in many parts of the Pennines are disintegrating. The beginning of the process is improvement in drainage; later, torrents break through the covering and channels are cut in the soft peat, which is carried away as mud and blown away as dust. The sheet of peat breaks up into islands, the islands shrink to hillocks, then these disappear and the ground is left ready for a new type of vegetation.

The moor with its thick, wet mass of peat must not be confused with the *Heath*, that is, the heath as it is understood in central western Europe. Heathland shows thin peat resting on sandy soil. It is one of those infertile habitats so much of which has been reclaimed by scientific treatment in Denmark, etc. The Scottish heaths are the great "grouse-moors" of the north and east Highlands. The North Yorkshire moors are heathland. The dominant plant is *Calluna vulgaris*.

The above are notes of the very scantiest; the student must make notes of his moor as he himself sees it.

CALCAREOUS GRASSLAND

The limestone hill-sides of the Pennines (Carboniferous limestone) carry grass communities which are nearly "natural," being only slightly altered by grazing. Their constituent species form a group sharply distinct from the grassland on siliceous soils. Three factors combine to make the habitat peculiar—the soil is usually shallow; it is usually dry owing to the rapid drainage by way of the many joints in the rock; it contains a very high percentage of calcium carbonate.

The turf over limestone is very close and uniform; the Sheep's Fescue Grass is the chief turf-former, and in places the Blue Moor-grass. Of common occurrence amongst the Grasses are Bulbous Buttercup, Eyebright, Yarrow, Bird's-foot Trefoil, Thyme, Plantains, Field Rush. Characteristic of this grassland is a long list of plants which are not often found except on calcareous soil; such are the Mountain Violet, the Small Meadow Rue, Rock-rose, Salad Burnet, Marjoram. They belong to the class of the *calcicoles* (p. 158) or lime-lovers. The *calcifuges* are scarcely ever found on limestone soils; they include Gorse, Broom, Heather, Bracken, Foxglove.

The reasons why a plant should avoid or should prefer calcareous soil are not clear. It may be that chemically the lime is harmful or favourable to their individual constitutions; perhaps the lime acts by modifying the strength of soil solutions; perhaps it alters the biotic condition of the soil; perhaps the normal scarcity of moisture over limestone is the factor concerned; perhaps the cause is to be sought in a combination of factors.

AQUATIC AND MARSH VEGETATION

Under this head will be considered the plants which grow in ponds, lakes and rivers, as well as those which grow on their margins. This is a study of communities which are dominated by the water factor, both as water in the soil and as water in which the plants may be wholly or partially submerged. It is a study of the distribution of plants in zones or belts, the number of which depends on the rate at which the water deepens. At one end of the series of zones is the wet soil adjacent to normally dry ground; at the other, deep water in which there may be free-floating, or rooted but submerged plants.

The results of the examination of such habitats may be set out graphically on a *transect chart*. The succession of plants growing in a line (taking an average of several) at right angles to the plant zones is ascertained. A line representing this is drawn on sectional paper, and the names of the plants, or symbols indicating them, are entered against this.

The following are general facts which enter into the ecology of water plants in their homes. They are affected by the amount of movement in the water, which may be the very still and possibly stagnant water of a pond, the fresher water of a lake, or the varying currents of rivers. The plant growing in the water is exposed to no checks from lack of moisture, but transpiration from submerged surfaces will be impossible. Stems supported by water require no expenditure on strengthening tissue. Generally the supply of salts in solution is ample for the plant's needs. The aeration of the water varies; in stagnant water, especially if much vegetation is present, carbon dioxide may accumulate to a great extent. In ordinary water there is less oxygen present than in air, but carbon dioxide, being readily soluble in water, exists in high proportion. The light which penetrates a few feet of water is both weakened and altered; this is one reason why the internodes within the water are long. Aquatic plants are favoured by the more equable temperature of their habitat as compared with that of land plants; this follows from the fact that water cools more slowly and heats more slowly than a land surface. The temperature of the soil of the marsh, however, is often very low; the air overlying the marsh tends to be colder and more humid than over the dry meadow adjacent. One extremely important factor is that all the fixed plants have their roots in muddy soil, continuously and absolutely soaked with water; this, of course, means that practically no oxygen can be obtained by the roots from the soil. Another point which is often illustrated is that water plants often destroy their own habitats. Many of them are " social " plants, spreading by rhizomes into deeper water as they collect soil round their stems and leaves; they thus gradually make firmer soil where they grow, and build up a habitat for dry-land plants which displace them.

A distinction is usually made between *aquatic* plants or *hydrophytes*, which grow actually in water, and *hygrophytes*, which grow with roots in waterlogged soil but with the rest of the plant above the water.

The swiftly flowing Stream. Very few plants are able to exist in the quick currents of a stream. They are limited to the thread-like Algæ which make the stones slippery, and to a few Mosses specially adapted to their place on the stones which they encrust.

Waters with moderate Flow. These include the slower rivers, the busy canal, the mill-stream, the part of a lake where a stream enters or leaves. In such situations the plants must be fortified against changes in the volume and speed of the water. The plant which is to withstand the current must be flexible and firmly rooted; both stem and leaves must yield to the stream. It is here that we find the longest, most ribbon-like leaves. In the deepest places (three to four feet) may grow the Pondweed *Potamogeton natans*, having leaves eighteen inches long, or the Arrowhead, the leaves of which in such a situation may be two feet long and less than an inch wide; both of these will be completely submerged. In rather shallower water there may be present that form of Water Crowfoot in which all the leaves are cut up into filaments and are under water; also the Water Milfoil, several Pondweeds and the Canadian Waterweed.

The Lake Waters. The lake margin may show several distinct zones; this applies also to some river-banks, and in less degree to ponds. Plants generally found in one are quite frequently found in the others.

Adjacent to the drier meadow-land may lie a strip which is perpetually moist. The plants are rooted in unfavourable soil, but their stems and leaves are aerial; growth may be rather rank and may include a fair number of species. The principal adaptation of plant to habitat is the great development of air-spaces in the tissues, through which the roots are provided with oxygen. Many have underground travelling stems which carry the colony of plants lakewards. Amongst the plants common here are Rushes and Sedges, Marsh Marigold, Spearworts, Loosestrifes, Water and Marsh Speedwells, Water Forget-me-not, Water Dropwort, Marsh Pennywort, Ragged Robin, Meadowsweet, Lady's Smock, Willow-herbs, Mints, Marsh Valerian, Watercress, Water Avens, Water Hemlock, etc.; of course these are not all to be expected in any one locality. These marginal semi-swamps are liable to flooding. Sometimes trees are the dominant members of the community, and they are invariably Alder or Willow or both; these thrive exceedingly well on wet ground.

The zones actually within the water vary greatly round any lake, and between lake and lake. Three broad belts may be identified.

(*a*) The comparatively shallow water is inhabited by plants which live with parts of stem and foliage under water at all times. They, too, multiply by rhizomes which bore through the mud and send up fresh vertical shoots; mud and vegetable debris accumulate amongst them, and in time are consolidated as new ground fitted for land plants. Many of them have slim upright leaves amongst which the lake-waves wash without doing any harm. Such are the Common Reed, Iris and Common Rush. The Arrowhead may be here, but its leaves stand straight up out of the water and *are* arrow-shaped, or they are rounded and lie on the surface. If Water Crowfoot is present, it may have both submerged dissected leaves and lobed floating leaves. *Polygonum amphibium* can adapt itself to this and to other depths of water, or can change to short stem and compact leaves if it is left stranded on a mudbank. In the shallow water may also be found the Bog-bean, the Horsetail and the Mare's-tail with narrow whorled leaves and branches, the floating rosettes of Water Starwort, the Flowering Rush, only the purple flowers of which show above the water, and an aquatic grass (*Glyceria fluitans*) whose long leaves float on the surface.

(*b*) The deeper water of the next zone may be the home of associations dominated by the Bulrush or the Common Reed—reed-swamps. These plants may grow so close together that no others have a chance; in other cases the vegetation is mixed, whilst much of the area may be free from them. The Reed Swamp Association may cover miles of shore. In more open communities may be Horsetail and Water Plantain, rooted and partly above water; Canadian Waterweed, sometimes free-floating, sometimes slightly rooted, always submerged; Bladderwort, rootless and under water; Frogbit with rounded floating leaves and a bunch of roots hanging in the water; Pondweeds rooted and submerged.

(*c*) At still greater depths may grow the Water Lilies, white and yellow. Their large round leaves float on the surface and are kept there by the lengthening of the stalks even if the water-level rises. Flowers and leaves spring from a stout rhizome embedded in deep mud. Bulrushes may venture out into these parts, only the inflorescence showing above the water. Many of the free-floating plants from shallower waters are to be found here also. Everywhere, including the deepest areas of the lakes, swarm microscopic plants which are spoken of as the *plankton* of the waters.

A small pond reproduces several features of the lakeside on a small scale. Its waters are badly aerated; they may contain profuse growth of small Algæ. Duckweed may cover its surface with its small leaf-like stems. Pondweeds may cover the bottom of it so thickly that they look like a miniature flooded forest. Water Buttercups may spread starry white flowers all over it.

Propagation of Water Plants. Pollination is uncertain owing to the scarcity of insects and the wastage of pollen in water. One or two plants (e.g. some of the Water Starworts) actually are pollinated under water. In most cases flowers are sent above the water even when no other part of the plant shows itself there. The Water Lily is insect-pollinated; the Pondweeds are wind-pollinated.

Vegetative multiplication is depended on far more than seed production. The prevalence of burrowing, horizontal stems accounts for the spread of many plants of "social" habit. Many others are propagated from fragments of stems which take root readily. They are dispersed by water currents; they (as well as seeds) are carried from lake to lake on the feet of water birds; they are carried from river to river along canals, clinging to the bottom of barges. Some aquatics prepare special buds in autumn, often well stocked with starch; when the plant dies down these are detached, become embedded in the mud and hibernate there. Examples of these are Canadian Waterweed, Water Milfoil, Frogbit, Water Soldier. Arrowhead forms solid, tuber-like buds; Duckweed loads itself with starch, drops into the mud and winters there.

Tissues of Water Plants. In the general ground-tissue the intercellular spaces may be enormously in excess of the space occupied by the cells themselves (Fig. 103). They form a continuous series of passages running throughout roots, stems and leaves. They are well illustrated in the Rush, the Water Lily, the Water Violet, Sedges, etc. This is a twofold provision. It serves for the storage of oxygen set free in the plant's photosynthetic processes; it allows free transference of oxygen from any place where it is absorbed to the other parts of the plant. Roots in particular require far more oxygen than they can get from the wet soil in which they grow; this is true both of marsh and aquatic plants. It has already been pointed out that, owing to the lower percentage of oxygen present in water, leaves immersed in it are at a disadvantage as compared with those in air. Another character connected with this is the absence of a definite cuticle in the epidermis of submerged parts. Stomata would be useless; they are either absent or do not function. In the Water Lily and other floating leaves, stomata are confined to the upper surface, which is coated with wax to prevent water from adhering to it. Air and water can pass through all parts of the submerged surfaces of aquatic plants with comparative ease. This gives a large absorptive surface through which also salts in solution can enter. There is thus little need for roots as absorptive organs; sometimes they are lacking, generally they are poorly developed and act mainly as holdfasts.

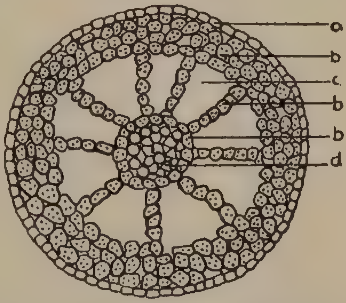

FIG. 103. POTAMOGETON: SECTION OF STEM OF AQUATIC PLANT

a, epidermis; *b*, cortical tissue with starch; *c*, large intercellular space; *d*, vascular tissue.

As the intake of water is so widely distributed, conducting tissue becomes nearly unnecessary; the vascular strands are excessively small, true xylem may even be absent, though phloem is never absent.

The weight of the plant is supported by the water, hence the poor development of strengthening tissue; what is present is concentrated near the centre where it best offers resistance to the pulling strains of currents of water.

A leaf under water is feebly illuminated. It is an advantage, therefore, that these leaves are thin and that chlorophyll is situated in the epidermal layer.

A SAND-DUNE

This bears one of the British sea-coast communities. The stages by which it is built up can readily be followed. Just above high-tide line certain plants establish themselves; drifting sand gets entangled amongst them, covers them; they survive this and grow up through the sand. The performance is repeated many times, and a mound of sand—a dune—is formed. From its surface protrude the dune-forming plants; within it, the sand is traversed in every direction by their roots and their underground stems. The dune owes its origin to these plants, owes also its continued existence to them. They behave as sand-binders. The most effective of them are the Marram Grass (*Ammophila arenaria*) and the Sea Couch Grass (*Agropyron junceum*). For a long time the dune surface may be unstable, mobile, liable to be excavated by wind. Gradually, however, it becomes "fixed." The assemblage of plants which gathers on it takes its character largely from that in the country immediately inland. It may include Sea Holly, Sea Buckthorn, Restharrow, Creeping Willow, Sand Sedge, Grasses; naturally, all these will not appear on any one dune. When the dune is young the seaward side may yet be bare sand, whilst the ridge is crested with Marram- or Couch-grass, and the landward side bears a fair number of other colonists. Only very slowly is a continuous covering of vegetation established.

The factor which dominates life on the sand-dune is the shifting of the sand. Other factors which are of consequence are the exposure to strong insolation and desiccating winds, the small amount of humus present, and the none too plentiful water-supply in the sand, though this last is not so marked as one might expect. Salt may be present, but the quantity is not great enough to make much difference. The dune habitat is a distinctly dry one, and the plants which live on it are distinctly xerophytic. Their leaves are distinguished by reduction of area, leathery cuticles, and inrolled margins.

A Salt-Marsh

The master factor here is the excess of common salt in the soil solution.

In the distance between the normal land vegetation and low-water mark a number of belts of marsh vegetation may be traced; they vary with the locality. From the sea shorewards they show a higher degree of stabilisation. In some places the Grasswrack (*Zostera marina*) actually lives submerged in sea-water. The association which exists nearest to this is that of the Glasswort (*Salicornia*). Then comes a tract bearing more varied vegetation—Sea Aster, Sea Plantain, Sea Lavender, etc. When the soil becomes better consolidated, good pasture-land is formed. Its dominant is the Sea-Grass, *Glyceria maritima*.

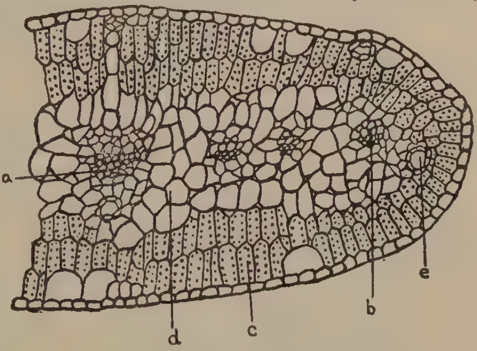

Fig. 104. Leaf of a Halophyte (*Crithmum maritimum*)

a, midrib; *b*, side-vein; *c*, palisade parenchyma containing chlorophyll; *d*, water-storage tissue, thin-walled, without chlorophyll; *e*, gland.

The high concentration of the soil solution makes the salt-marsh a physiologically dry habitat. The plants growing on it are highly xerophytic, having some characters which are peculiar to this form of drought. They are classed as *halophytes*. The chief peculiarity is the pronounced succulence of shoots and leaves; sometimes the latter are very small. The soft juicy tissues consist of large thin-walled cells; they are water reservoirs in which dilute solutions can be accumulated (Fig. 104).

CHAPTER XXV

SEEDLESS PLANTS

Although early botanical work is naturally directed chiefly to the Flowering, or (better) Seed-bearing Plants, yet no real student can ignore the vast crowds of growing things which never reach the beauty of the flower. The next pages will deal with these latter only in the sketchiest fashion, but they may act as a guide towards an intelligent view of the plants until they can be studied more thoroughly. They are not really uninteresting; many amateurs have found one branch or other of them attractive enough to adopt as a hobby.

To illustrate the principal types I shall suggest a few common examples from which one can gain a good deal of information with the naked eye and a simple lens.

The following table gives the chief divisions of the Plant Kingdom; connect it with the tables on pages 79–93.

Seed-bearing Plants (Phanerogams).		Seedless Plants (Cryptogams).		
Spermophyta.		Pteridophyta.	Bryophyta.	Thallophyta.
Angiosperms (ovules and seeds enclosed—i.e. fruits).	Gymnosperms (ovules and seeds naked—i.e. no fruits).	Ferns. Lycopods. Horsetails.	Mosses. Liverworts.	Algæ. Fungi. Lichens.
	Pteridosperms: fossil forms.			

The phylum of the Spermophytes is now completely separated from the other three phyla by a deep reproductive gap. Recent research amongst fossil plants has, however, shown that the gap did not always exist; there were intermediate connecting forms. The latest evolved, and, speaking generally, the most economically effective reproductive organs are found amongst the spermophytes. Much simpler, less specialised modes of reproduction are the rule in the case of the seedless plants. These were the plants which formed the bulk of the vegetation in the forests from which our coal-beds were formed. It is possible to obtain by patiently piecing together the fragments of plants preserved as fossils in the Coal Measures, an amazingly vivid idea of complete plants, not only of external characters, but of such minute details as the spiral and annular thickening in the walls of vessels, the stomata, the nature of the spores, even the nuclei of protoplasm. Bit by bit, the palæontologists are making out a table of descent for the plants. It appears, for instance, that very many of the plants of the Coal Measures belonged to the Pteridophyta. Modern plants of that phylum are almost all small and herbaceous; their Carboniferous ancestors were often tall trees, with hard wood and thick bark. Fern-like foliage, small and also very large, is the commonest by far amongst these fossils. At first it was thought that all of it belonged to Ferns. Then on certain fronds were discovered structures which proved to be primitive forms of seeds. For these fossil plants there has been created a group intermediate between the seedless and the modern seed-bearing group, namely, the *Pteridosperms*. Nevertheless, there were no *flowers* in these woods.

PTERIDOPHYTA

A. **Ferns.** The chief characters of this group you will find clearly displayed among the Ferns.

Common ferns like Bracken or the Male Fern are suitable to begin with. Take up and cut transversely the buried stock: vascular tissue is present, though in its elements and in its arrangement it differs from that in Flowering Plants. The foliage consists of repeatedly divided fronds; branches arise, not in the axils of leaves, but usually as outgrowths from the bases of leaves. The Tree-ferns branch very little.

Very prominent as the season advances become small outgrowths on the under sides of some of the leaf pinnæ: they are definitely arranged according to plans which vary with the species; they are always associated with veins. When the membranous shield covering one of these is removed, the magnifying-glass brings to light a number of cases filled with spores, *sporangia* (Fig. 105). A group of sporangia is a *sorus*. Many thousands of spores, dust-like in size, are shed from a single pinna and float away on the air. Countless in their multitudes and moving lightly as the air itself, they naturally are amongst those first at the post in the race to get possession as colonists of every new and likely place of settlement. A well-known instance is that of Krakatau, an island in the East Indies, of which the vegetation was absolutely swept away in the volcanic eruption of 1883. After a few lowlier forms, the first plants to reappear were Ferns and Mosses; their spores must have travelled at least twenty-five miles, the distance from the nearest island. In new-formed volcanic islands in open seas, Ferns are amongst the first plant settlers.

Try some of these brown Fern spores on damp soil. They germinate as a seed might do. They are not seeds, however. If you worked back into their history you would find that the spores are single cells which have arisen simply by division of certain cells of the parent; nothing comes to light which corresponds to that union of a male and a female element which constitutes the fertilisation process by means of which an ovule becomes a seed.

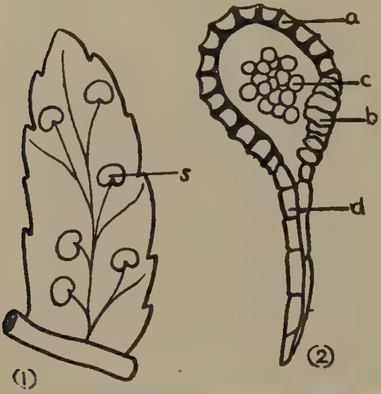

Fig. 105. Fern: Spore-bearing Organs
(1) Pinna of frond, with sori; (2) Sporangium.
s, sorus, covered by kidney-shaped shield; *a*, annulus, a ring of cells with unequally thickened walls; *b*, place where, owing to thinness of walls, a split occurs when *a*, contracts; *c*, a few of the spores; *d*, stalk of sporangium.

Your spores germinate. But the astounding discovery you make will be that the things that they give birth to are *not ferns*. First, there comes into being a thin, green filament—merely one row of cells—which loses no time in providing itself with a root-hair or two. By growth and division of cells there develops from this a flat, green plate of tissue, heart-shaped, and not more than a quarter of an inch in diameter. It is fixed and fed by root-hairs. This plant is known as a *prothallus*. In the shady corners of a fernery, plenty of these little prothalli may be found (Fig. 106).

The subsequent history of the prothallus is very remarkable, and it is unfortunate that all that can be given here is a bare summary of it. The central portion of the plant, lying behind the indentation, thickens considerably. On this cushion of cells are formed male and female reproductive organs, of which our Fern showed never a trace. When the male organs (*antheridia*) are ripe and can get a little moisture, they burst open, and the male cells (*spermatozoids*) escape. They are queer spiral beings, each waving a tuft of cilia at one end of itself. A minute quantity of water is enough for their swimming exhibitions, and they quickly direct their progress towards the female organs (*archegonia*). The end of the flask-like archegonium which lies at the surface of the cushion tissue breaks down into mucilage when moistened, whilst at the same time malic acid is secreted; this it is which attracts the spermatozoids. One or more of them pass down the tube-like neck of the archegonium, and one fuses with the *ovum*, or egg cell, which lies at the bottom of that organ. Here we have a clear case of fertilisation. A new plant results from it, one which for a time keeps in connection with the prothallus, and actually feeds on it. A root is formed; a first leaf rises between the lobes of the prothallus; it is a very simple leaf, quite unlike the much-divided fern frond. One by one, as they are added, the leaves become more like the adult type, and finally a Fern plant is built up.

Looking back over the facts we sum up: *a*, a conspicuous Fern plant, gives rise by means of asexually formed spores to *b*, a brood of insignificant-looking prothalli which bear sexual organs and rear a sexually produced offspring, *c*. This *c* generation is a return to the *a* generation. The Fern plant constitutes the *sporophyte*, and the prothallus the *gametophyte*; whilst the whole cycle of events is known as an *alternation of generations*. You will find, in your advanced studies, that it is of wide occurrence, and that, in disguised form, it even creeps into the life of the Flowering Plant: meantime, you may wonder over it.

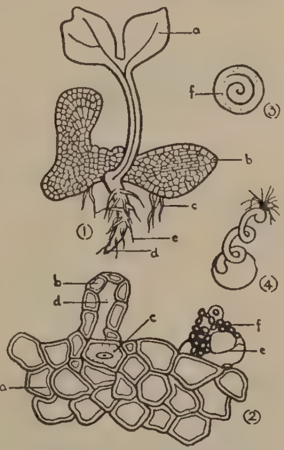

FIG. 106. FERN: PROTHALLUS

(1) Prothallus with young fern-plant. *a*, first leaf of fern plant; *b*, prothallus; *c*, rhizoid; *d*, primary root; *e*, secondary root. (2) Portion of prothallus with an archegonium and an antheridium. (3) Spermatozoid still enclosed in its mother-cell. (4) Free-swimming spermatozoid.

a, cells of prothallus; *b*, cells of neck of archegonium; *c*, egg-cell; *d*, neck-canal, the cells of which have broken down into mucus; *e*, wall of antheridium breaking down; *f*, spermatozoids.

B. **Lycopods.** In most greenhouses you will find on the soil of flower-pots a little of a plant which you may mistake for a Moss. It is one of the Lycopods, *Selaginella*. Its straggling stems lie almost prostrate in a loose mat. They are bi-forked, and from the forks drop root-like outgrowths. These *rhizophores* are not true roots, as is shown by their root-tips and by their mode of origin within the stem. After reaching the ground they provide themselves with root-caps, and grow like roots afterwards. All parts of the plant contain vascular tissue which possesses xylem and phloem elements. The thin stems are covered by four ranks of small leaves, two lines of which are much smaller than the other two (Fig. 107).

Selaginella, like the ferns, has two generations taking their turn in its life-story. The familiar plant of the greenhouse is the spore-producing member of the cycle. There is here a difference from the fern; the spores are aggregated on special erect leafy shoots, known as *cones*. Further, there are two kinds of spores—a most distinctive character. In the axils of the upper leaves of the cone are sporangia containing small spores, *microspores*, which are male. Within the sporangia of the lower leaves are large female spores, *megaspores*. Then comes in the second generation, which is of double form. The male and female spores of the first generation do not unite, which may surprise you. A microspore develops independently, but only a little way; it forms a prothallus of a few cells and this miniature male plant contrives to produce a few spermatozoids. The megaspores form larger prothalli, embedded in which are female organs. This generation is therefore unisexual. Again, as in the Fern, the sperm cell swims to the female prothallus; it is probably chemically attracted. Fusion of female and male elements takes place, and results, ultimately, in a *Selaginella* plant.

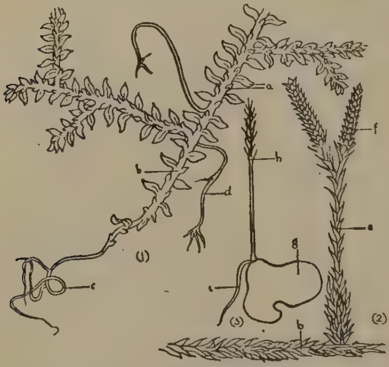

FIG. 107. LYCOPODS

(1) *Selaginella*, plant; (2) *Lycopodium clavatum*, fertile branch; (3) *Lycopodium clavatum*, prothallus and young plant.

a, two types of leaf; *b*, prostrate stem; *c*, root; *d*, rhizophore; *e*, upright stem; *f*, cone bearing spores; *g*, prothallus; *h*, first shoot of young plant; *i*, first root.

Selaginella is sometimes called a Club-moss, but the true Club-mosses are the Lycopods of the moors and the hills (Fig. 107). They are plants of lowly growth mingling with Grasses and Heather. Their stems are slender, their leaves small, and their habit often hard and wiry. They resemble *Selaginella* in a general way, but they have only one kind of spore and one kind of prothallus. Again there are seen two generations in alternation.

C. **Horsetails.** It is easy to get specimens of that tiresome weed, the Horsetail (*Equisetum*). Its stiff, brittle stems having their branches always in whorls, and their leaves reduced to almost nothing, are easily identified. Long rhizomes travel far underground; it is nearly impossible to get rid of an established plant, as a new plant may spring up from any single node which is left behind.

The vascular tissues in *Equisetum* are unique amongst living plants, but they match, nearly cell for cell, the tissues of the *Calamites*, tree forms belonging to this group which were dominant plants in the coal forests.

The phenomenon of alternation of generations occurs in the life of *Equisetum*. The Horsetail plant is the sporophyte; the sporangia are grouped on cones at the tops of the branches, sometimes on special branches appearing in early spring; they shelter under stalked disks (*sporophylls*) crowded together on the cone. The spores are green and are of one kind (Fig. 108).

Prothalli are formed, some of which are male, some female; at times both sexes are present on the same prothallus. From the union of the sexual elements springs the sporophyte generation, as in the Ferns and Lycopods.

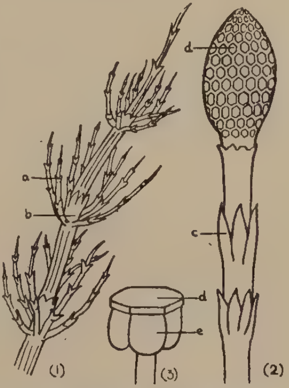

FIG. 108. HORSETAIL (*Equisetum*)
(1) Sterile shoot. (2) Fertile shoot; (3) Sporophyll with sporangia. *a*, whorls of branches; *b*, sheath of united and reduced leaves through the bases of which the branches have broken, thus appearing below them; *c*, sheath of leaves on fertile shoot; *d*, sporophyll; *e*, sporangia.

BRYOPHYTA

Alternation of generations prevails in this phylum also. There is, however, a great reversal in the relative sizes of the individuals of the two generations: it is the sexual plant which is now that popularly known as a full-grown plant; the asexual is commonly referred to as a fruit of that plant.

A long leap downwards in the climbing path of evolution has been taken by us in passing from *Pteridophytes* to *Bryophytes*. Nothing of lower rank than the former possesses vascular tissues —those highly specialised conducting tracts with their firm, fibrous, supporting cells. When these tissues made their appearance in the plant race it became possible for the plant to grow tall and to stand erect. They gave the strong trunk to the tree, and they renewed perpetually the water store perpetually being drained from the foliage of the tree. Until that epoch in plant evolution arrived, nature saw only the lowliness of the Moss and the weakness of the Alga. These we go forward to study now.

A. **Mosses.** You must have noticed a very compact, rather dull-looking Moss, about half an inch high, which frequents the tops of walls, and garden paths (*Funaria hygrometica*). It seems to be carrying a crop of some sort at all seasons—hair-like stalks surmounted by capsules. Take a good look at this Moss and compare it with others such as the Hair-moss (*Polytrichum*) and Bog-moss (*Sphagnum*) (Fig. 109).

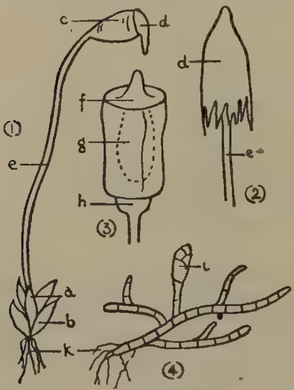

FIG. 109. Moss

(1) Fruiting plant of *Funaria*; (2) Capsule of *Polytrichum*; (3) The same, further enlarged, the cap removed; (4) Protonema.

a, the foot of the seta, all above *a* being the sporophyte or spore-bearing generation; *b*, the plant which bore female reproductive organs; *c*, capsule containing spores; *d*, cap (calyptra); *e*, seta; *f*, lid of capsule; *g*, spore-region; *h*, green assimilatory region; *i*, bud, from which moss-plant arises; *k*, rhizomes.

What we call the Moss plant seems to resemble the higher plants in possessing roots, stem, leaves and fruits in the usual way, but this appearance is deceptive. The roots are thread-like, many-celled root-hairs distinguished as *rhizoids*. The aerial parts have distinct epidermal and cortical tissues, but only elongated central cells in place of elaborate vascular strands. The so-called fruits are not strictly part of the plant at all. Water is absorbed all over the surface of the leaves; this must be correlated with the meagre root absorption and the poor provision for water conduction.

But mark this. The Fern plant was the spore-producer; the Moss plant is the sex-producer; herein lies the reversal of rôles. In some Mosses you easily find quite pretty flower-like terminations to the shoots, faintly tinted with red. In the centre of these delicate rosettes of leaves lie the male and female organs, together with some juicy hairs. In some cases, both sexes are present on one plant; in some, on separate plants. Fertilisation requires the presence of water; this is in order that the spermatozoid may travel to the female organ, in which lies the egg-cell with which it is to unite.

The fertilised egg cell develops into a plant which represents the second generation. The great new feature is that this plant never parts company with the preceding generation. It is the structure which the casual glance may mistake for a Moss fruit. It looks a poor thing to be a complete plant. The thin stalk (*seta*) is fixed by a pointed "foot" in the tissues of the Moss plant—in its cradle. The capsule at the top of the seta is covered over by a loose cap of tissue carried up from the parent. The capsule is a spore-chest. The lower part of it is green, possesses stomata, and functions as a green leaf; it is the assimilating region of this much-reduced plant. Water and mineral salts come to the sporophyte by way of the gametophyte, through the "foot"; the rest of its needs it can supply independently.

The spores when favourably placed lead to the production of Moss plants, but not directly. There is an intermediate stage, the length of which varies with the species and which is limited to a web of filaments resting on the soil; it is known as a *protonema*; it may recall to you the first filament of the prothallus of the Fern. From one of its cells the Moss plant grows.

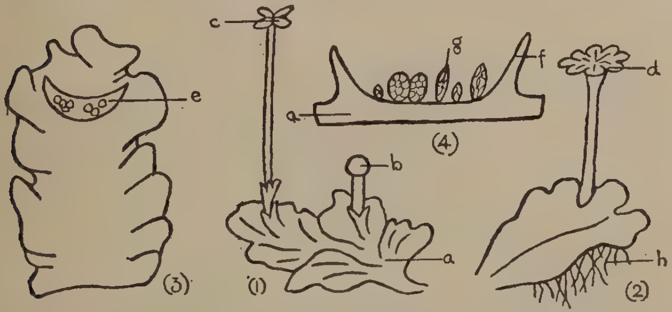

Fig. 110. Liverwort

(1) Thallus bearing fruits; (2) *Marchantia*: portion of thallus bearing male sexual organs; (3) *Lunularia*: portion of thallus bearing one crescent-shaped cup; (4) Section of cup, showing attachment of young gemmæ.

a, thallus; *b*, spore-capsule, closed; *c*, spore-capsule, open and empty; *d*, stalked organ bearing antheridia on under side of the "umbrella": the female organ is more divided; *e*, gemmæ cup; *f*, section of a wall of a cup; *g*, gemmæ; *h*, rhizoids.

Finally, remember that the prothallus of the Fern is the generation equivalent to the Moss plant, and that the spore-filled capsule on its stalk corresponds to the big Fern plant.

B. **Liverworts.** Search in dim, moist corners under stream-banks, near waterfalls, round cattle drinking-troughs and such-like places, and you will probably find patches of flattened-out plants pressing close to the ground. The villagers will speak of them as Mosses, but they are Liverworts.

Mosses and Liverworts agree in having a fair-sized gametophyte generation and an insignificant sporophyte generation. The most lowly of the Liverworts attain to no semblance of stem or leaf, and their apology for roots consists of rhizoidal root-hairs sprouting from their under surfaces. Their vegetative parts are reduced to a more or less freely lobed plate of green tissue; this brings plant form down to a *thallus*—a great drop. The thallus resembles a magnified fern prothallus, and really corresponds to it in status. The thallus lacks even the rudimentary conducting strands of the Mosses, what looks like a midrib being only a thickened strip of thallus. In a few Liverworts the form is suggestive of little stems and leaves; again there is no specialised conducting tissue (Fig. 110).

The sexual organs are either sunk in protected pits in the thalloid substance (in the lowly forms), or raised on stalks (in the more advanced). The former may be recognised as small, dark specks; the latter are pretty umbrella-like bodies. Fertilisation is essentially the same as in the Mosses. It will have been realised that water is always required for this in order that the spermatozoids may make their way to the archegonium; drops of rain or dew suffice.

The product of fertilisation is again a stalked capsule, containing spores. For months it may crouch on the thallus, no bigger than a pin-head. Then in spring the stalk shoots up inches in a day, the capsule opens, and the spores set out on their travels. As in the Mosses, a spore's function is to initiate a thalloid plant—the next generation. There is in the Liverworts, as in the Mosses, an intermediate protonema stage, but it is small, and soon passes over into a thallus.

Quite frequently the thallus generation is propagated by vegetative means. On the upper surface of the genus *Marchantia* you will often find attractive little circular cups; on *Lunularia*, the cups are crescent-shaped. Their contents, quite loose when mature, are piles of tiny green flakes. Each one is a potential thallus consisting of a few cells; falling on moist soil, a cell or two will strike down as a rhizoid, and the future entails no more than growth and subdivision of cells till a full-sized thallus is there.

THALLOPHYTA

The Thallophytes include all plants below the Bryophytes. No one of them is differentiated into roots, stems or leaves; neither does any one of them possess vascular tissues. The plant body is a *thallus*, sometimes one-celled, sometimes many-celled. The classification under the heads of Algæ, Fungi, Lichens, Bacteria, is only approximately sound, but it is serviceable.

A. **Algæ.** This is a very extensive group and includes individuals so utterly unlike that you can scarcely credit their being near relations. *Protococcus* is one of them, and that you will remember as a single microscopic cell; *Macrocystis* is a giant brown seaweed many hundreds of feet in length. Some seaweeds float hither and thither unattached; some look as if glued to the rocks, whilst some have outspread claws which look as if they were gripping them. The scum on a stagnant pool is algal; the slippery stone in the brooks is green with filaments of one Alga, and the outside of a neglected flower-pot with another. Within the groups one can pick out a series which will illustrate the steps by which complex plant bodies have been built up. First, there are many formed of one cell only and that free-moving. An advance is made when the cell divides, and by repeated divisions a chain of cells comes into existence; this, too, may be free-floating, or by one end it may fix itself down to one spot; *Spirogyra* and *Ulothrix* illustrate these (Fig. 111). Then the filamentous shape may widen and thicken into more massive forms. It may become a lobed and thalloid plate rather like that of a Liverwort; it may go as far as to imitate the external appearance of roots, stems and leaves. In no case are the tissues modified to perform specialised functions beyond the lengthening of the central cells for conduction, and the locating of colouring matter in those near the surface, for assimilation. One curiously isolated detail is the occurrence of sieve-plates in some of the long cells of the giant seaweed *Laminaria*.

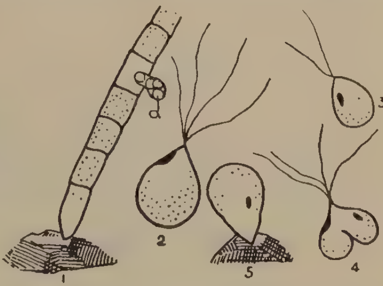

FIG. 111. ULOTHRIX

(1) Part of filament attached to stone. Less highly magnified than (2)–(5); (2) Asexual zoospore; (3) Sexual zoospore (gamete); (4) Two gametes partly fused; (5) Zygospore, attached.

a, envelope containing zoospores escaping from cell of filament.

Algæ contain chlorophyll and are able to utilise air and light as do the higher plants; there is this difference, that for the assimilation product starch there may be substituted a substance peculiar to Algæ, *laminarin*. Pigments other than chlorophyll may be present, notably a brown and a red; these will dissolve out if the alga is placed in fresh, hot water, leaving visible the green which they had been masking.

The Alga absorbs its gases and its soluble salts over its whole surface. Within a field cattle-trough fed by a gentle inflow of water, when the sun is shining on it, one may chance on a pretty exhibition of algal activity. The sides lined with fluffy green Algæ glitter with little gas-bubbles. Sweep your hand over them and a rush of gas streams up to the surface. The gas is chiefly oxygen, set free by the algal cells which are utilising the sunshine to break up carbon dioxide in order to get its carbon (p. 106).

Many modes of reproduction are practised amongst the Algæ; we can but barely mention them. In a few instances they include processes which may be taken as a foreshadowing of that alternation of generations which we have met with so often. Apart from these hints of the future, the outstanding fact in algal reproduction is the absence of this cycle.

Sometimes an Alga multiplies merely by breaking up into sections. Many green Algæ reproduce through asexual spores of a peculiar kind. The protoplasm of a parent cell rounds itself off and forsakes the cell; cilia, which are hair-like protrusions of protoplasm, grow out from it (cf. p. 98), and for an hour or so it uses these to swim around. Then the cilia are withdrawn and the spore settles down to start life as a new plant. Such spores, animal-like in movement, are named *Zoospores* (Fig. 111).

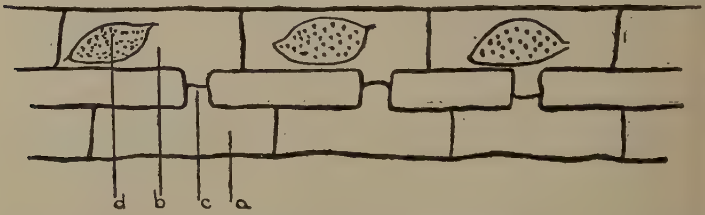

FIG. 112. SPIROGYRA: CONJUGATION

Shows portions of two filaments in which pairs of parallel cells have conjugated. *a*, empty cell; *b*, cell into which the contents of *a* have passed; *c*, the fused outgrowths from *a* and *b*, still showing the place of fusion; *d*, fused protoplasm of the cells *a* and *b*, distinctly rounded off except at the ends of the masses.

A primitive type of sexual process appears, in which the two reproductive cells seem to be exactly alike, i.e. there is no distinction between the male and the female. This is spoken of as *conjugation*. One instance of it is found in *Ulothrix*, a thread-like fresh-water Alga which prefers running water. In this plant, within one of the cells of the filament, there may come into being a brood of pear-shaped, ciliated cells, mere specks of protoplasm. They escape from the cell and move about for a time. Then some of them fuse in pairs, and the sexual act is accomplished. The cilia are withdrawn; the new spore (*zygospore*) becomes attached by one end to some object and develops into a filament.

Conjugation with a difference occurs in *Spirogyra*. Two filaments arrange themselves side by side; a cell from one filament sends out a projection in its wall towards a similar projection in the cell lying opposite to it in the parallel filament. The two processes meet, and their walls break down where they touch, thus opening a passage from cell to cell. In the meanwhile the protoplasm in the two cells has been gathering itself together in the middle of the cell. That within one of the cells is more active than the other, and moves through the passage into the other cell, where it unites with the protoplasm waiting there for it. This marks a step towards the quick-moving spermatozoid of Mosses, etc. (Fig. 112).

In *Vaucheria*, sexual and asexual reproduction are possible within the same individual. Compare this with the sexual and asexual individuals in, say, a Moss.

In many of the large seaweeds reproduction is always sexual, and the cells are definitely male and female. In the Brown Algæ the fertile branches are easily recognised. Sometimes they are orange, sometimes dark olive-green. All over the frond, visible to the naked eye, are scattered rough specks; with the lens they can be made out as minute swellings of tissue from an opening at the top of which stick out a number of hairs. The swellings are hollow; some of them contain only hairs, but mixed with the hairs in others are the male reproductive organs (*antheridia*) within which are formed the male sexual cells, the spermatozoids. In larger chambers rest the green egg-cells. The hairs secrete mucus. When ripe, the orange antherozoids embedded in mucus and the green egg-cells with their mucus ooze out of the chambers and have opportunities of mingling together. Fertilisation thus takes place outside the parent body (Fig. 113).

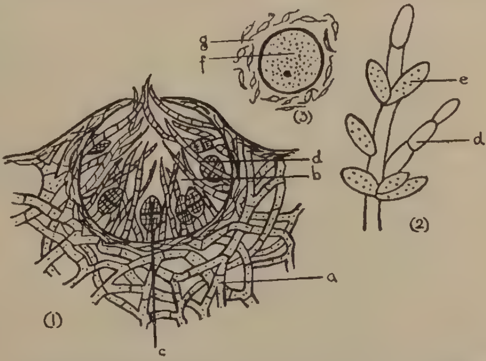

Fig. 113. Fertilisation of Brown Alga (*Pelvetia*)

(1) Chamber containing oogonia, each with two egg-cells; (2) Group of antheridia from another plant; (3) Egg-cell surrounded by motile spermatozoids.

a, tissue of thallus; *b*, chamber (conceptacle); *c*, oogonium; *d*, sterile hairs, mucus-producing; *e*, antheridium; *f*, egg-cell; *g*, spermatozoid.

B. **Fungi.** There are over sixty thousand known kinds of these degenerate but seemingly successful relations of the Algæ. Devoid of chlorophyll and, therefore, of the power to build up organic food for themselves, they take it ready-made from either the dead or the living; they are either saprophytes or parasites.

White moulds and green moulds; moulds growing on every imaginable organic substance—bread, jam, old boots, wall-paper; are all Fungi. A Fungus causes a potato disease; the "damping off" of seedlings is the work of Fungus. Then there are mildew on Roses, scab on Apple-trees, rust and smuts on Wheat; whilst the tribes of Puffballs, Mushrooms and Toadstools are not likely to be overlooked.

A Mushroom is a very easy type through which to introduce fungal arrangements. The purely vegetative part of it stays below ground; the part which in a night is born into the day is the spore-carrying structure. Look at the latter first. From the under side of the umbrella-like cap hang down delicate leaves (*lamellæ*). The free faces of these are velvety with a close growth of long cells. From the tips of some of these cells little bits are partitioned off; these morsels are spores—surely nothing could be more simply done. Multitudes of them float off from one fungus. Lay a mushroom, lamellæ side downwards, on a piece of white paper; it will not be long before a pattern of the lamellar scheme is laid out in spores on the paper. These asexual spores give rise directly to mushrooms, so there is no alternate generation here (Fig. 114).

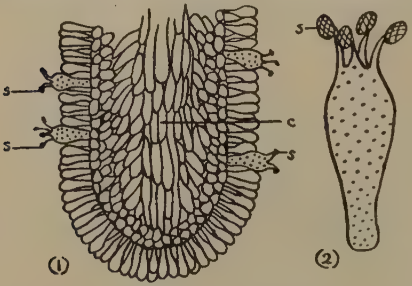

Fig. 114. Mushroom

(1) Section of lower edge of lamella; (2) Spore-bearing cell from external layer of (1). *s*, spore; *c*, elongated conducting hyphæ. Only a few of the spore-bearing cells are shown in (1).

From the spores originates the tangle of filaments or hyphæ which constitute the very simple food-collecting part of the Mushroom, that which is buried. The mass of filaments is known as a *mycelium*. A hypha is nothing more than an abnormally long cell; it contains within its cytoplasm, however, numerous nuclei (cf. *Myxomycetes*, p. 99). Some hyphæ are irregularly divided up into compartments by septa. No starch is found in hyphæ, but abundance of oil globules and glycogen (cf. Yeast, p. 108). Sometimes large Fungi are brightly coloured; the colour is situated in the cell walls.

The mycelium does not vary much amongst the larger Fungi; it is the reproductive characters which are used in classification.

Asexual habits are found in all Fungi. The spores are of various forms and arise in many interesting ways. Simple modes of sexual reproduction occur—either regularly or in special conditions of drought, etc. Examples may be found both of the case in which the uniting spores are of two distinct sexes, and of that in which there is no obvious difference between them.

In *Phythium*, which is responsible for the destruction of over-watered, under-aerated Cress seedlings,—as in some others—the asexual process requires moisture in which the ciliated zoospores may move; in this there is agreement with Algæ. Most Fungi have succeeded in dispensing with the water, and are the better suited for existence on land.

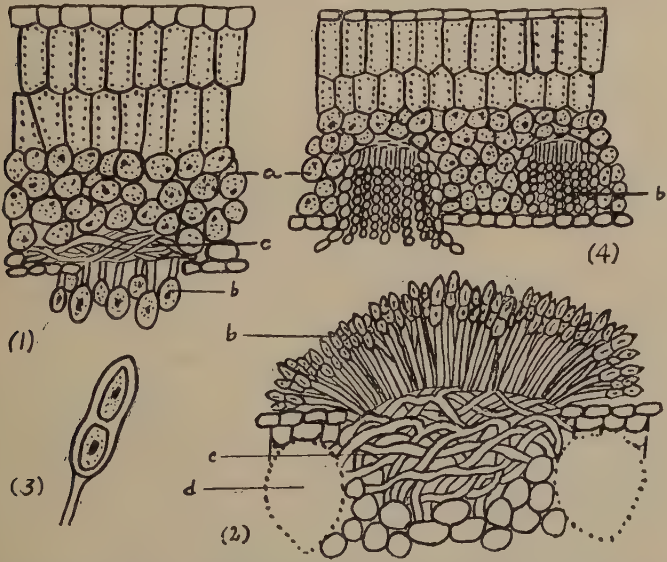

FIG. 115. "RUST" OF WHEAT: *Puccinia graminis*

(1) Single-celled spores (uredospores): red rust of Wheat; (2) Two-celled spores (teleutospores): mildew or black rust of Wheat: resting spores which travel to the new host after winter rest; (3) Single teleutospore; (4) Spore cups on under side of Barberry leaf (æcidiospores): one open, the other closed.

a, spongy parenchyma; *b*, spores; *e*, broken down tissue and hyphæ; *d*, vascular bundle.

Plant-history is full of puzzling events, and in some of them Fungi are the actors. Take the case of the " rust " of Wheat, those red streaks which break through the epidermis of Wheat and other Gramineæ. This robber leads a double existence. One part of its career is spent on the Wheat, and this it winds up by producing spores of more than one kind. Certain of these spores find that the host on which they were born is of no further use to them and they desert it.

If they manage to reach a Barberry leaf, they adopt it as a host and start afresh there. The infected leaf swells up into minute patches; by and by, on the lower surface of the patch, clusters of dainty yellow cups arise; within the open cups are displayed strings of spores. These break away in succession and are ready to begin a new game of pillage. They can do this only if they can win back to a Gramineæ leaf again. If they do, they at once set to work. First they thrust out some of their protoplasm through thin places in the spore wall in order to form hyphæ. The hyphæ prowl about till they find stomata in the epidermis. They push inwards through these, and commence literally to eat a way into the tissues of their host. They accomplish this by means of the solvent, digestive power of the enzymes or ferments (p. 109) which are secreted by the tips of the hyphæ. The hyphæ actually penetrate the cells and absorb their contents (Fig. 115). *Ranunculus Ficaria* is a host for more than one kind of Fungus: two of them are "rust" Fungi whose attacks cause distortion and decay of the leaves. Meadow Grasses are the second hosts in this case.

Such double domiciles are by no means uncommon amongst Fungi.

Fungus spores are turned out in countless millions. They are ethereally light and the air is peopled with them. They hold on tenaciously to life, withstanding heat, cold and drought. Some of them, when food and water are failing, encase themselves in thick walls and go to rest for a time. From all which we can understand how it is that organic matter, dead and living, so surely and so rapidly falls a prey to fungi.

The universal prevalence of Fungus pests and the swiftness with which they may get a strangle-hold on our crops make it imperative that the scientist should step in and help the farmer and the gardener in their battles against them. Potatoes, Turnips, Apple-trees, Plum-trees, Grains—all need protection. Agricultural research stations all over the country have been extending their work in this direction. It is a most interesting and useful botanical field, which students might more often consider in choosing a career.

There are two main lines of attack on the armies of little plagues:

(1) Within the same species of host plant there may be varieties on which a particular Fungus thrives, whilst there are other varieties which are never affected. To produce and cultivate such immune varieties, and at the same time to retain in the crop valuable qualities like high yield, etc., is one of the aims of the plant-breeder. One instance of this is the trials which are being carried on to secure marketable varieties of Potato which will resist the Fungus responsible for wart disease.

(2) The second task is to find out at what stage in its history and by what agents the pests can most surely be killed. Very searching

tests are being made on the efficacy of various sprays and washes (e.g. Bordeaux mixture, tar distillate, sulphur).

(3) The necessity for a third line of investigation has recently been disclosed. Just as a human body when "run down" succumbs more readily to infection, so, it appears, behaves a plant. If it is in an unhealthy condition owing to wrong cultivation, it may yield to a fungus which otherwise it is able to resist. For example, a case is quoted of a grower who found that his Plum-trees were suffering from a Fungus disease called "die-back," and who incurred heavy loss before it was discovered that the cause lay in the trees having been planted too deeply. Weak and unhealthy cell walls are likely to make easier the work which the fungal hyphæ have to do in destroying them. Hence, when fungal disease is spreading unaccountably over a crop, it is necessary to investigate the general condition of the crop plants themselves.

(4) A disturbing fact which was noticed lately is that new "strains" in a fungal species may appear suddenly. Although outwardly indistinguishable from the original strain, they may behave quite differently, deserting one host and adopting another. So at the Rothamsted Research Station (to mention one) they are breeding Fungi, watching for new strains and testing new hosts.

C. **Lichens.** They are the pioneer colonists on bare rock; they are the last stragglers left to endure the hardships of the highest mountains and the highest latitudes. On the grey mountain limestone, the grey encrusting Lichens are scarcely distinguishable from the rock they grow on; spreading as round, close-fitting thalli they may deceive you into thinking they are cross-sections of the fossil corals which the rock harbours. Pale yellow, rich yellow, yellow tinged with green, other Lichens may beautify these rocks—an exquisite harmony of colours. The stone wall, the gate-post and the tree bark may be decorated with warm orange or shaded grey; the Lichen-form here is of looser growth, free along its edges. Hanging tufts like coarse grey hair make old branches look still more hoary. On the moor, beneath the Heather, hide branching Lichens, mimicking little old shrubs. Under the Arctic snows are hidden still larger forms of Lichen on which the reindeer feed. The seashore too, even where the tide washes over, has its Lichen people.

And what are Lichens? Algæ demand water; Fungi demand ready-made food; Lichens demand light. The Lichen can, for a time, dispense with water quite cheerfully; it merely curls up till it looks, and is, as dry as dust. It makes no undue fuss about food apparently, since it so often chooses to live on a stone. Why?

A Lichen stands for one of Nature's strangest business arrangements, a remarkable partnership. Let a flat Lichen be sectioned downwards (Fig. 116). The uppermost and the undermost layers, A and B, remind you of an extremely compact mass of fungal filaments. Some of them, D, run down into the stratum on which the plant is growing. They *are* fungal hyphæ. Embedded within the meshes of the looser zone of the filaments, C, lie cells which are green and therefore not fungal. They are Algæ. So the whole affair has the look of a community. In a community, individuals should be mutually useful: these are. The hyphæ get from the soil the water and mineral salts needed by the community; their connection with the Algæ is actual, so that they can share with these, which have no means of supplying themselves with water. The Fungus may not be able to get any organic food from the substratum, but it draws in parasitic fashion from the Algæ. These latter, by virtue of their chlorophyll, can manufacture sugar, etc., if they can get air and light. The unicellular Algæ multiply by simple division, hence no water is required for motile spores. It will be clear, then, that by the terms of this ingenious co-operative society, the Algæ need not bother about drink, nor the Fungi about food. The tough hyphal web, too, is an excellent shelter for the more delicate green partner.

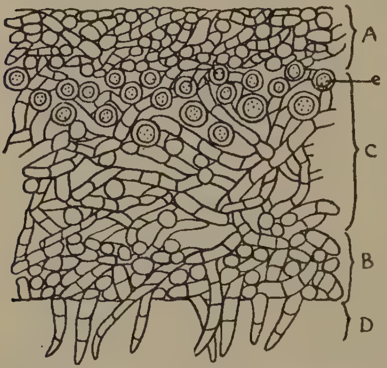

Fig. 116. Lichen (Highly Diagrammatic)
Lower part of c is free from *e*, the green cells.
For description, see text.

This is an example of *symbiosis*. By experiment it has been proved that the two forms of plant can, on occasion, live apart, and also can be identified as belonging to certain groups of Algæ and Fungi. To do this, the algal cells must be kept moist and shaded, and the hyphæ must be given a nutrient solution. Even more wonderful is it to watch a Lichen building up a society in public, as it were. A few cells and a few hyphæ; the extension of the latter towards the former; the entry of a sucking tip into a green cell; and, after many repetitions, the web of hyphæ and the imprisoned Algæ.

There is a pretty grey Lichen called *Cladonia*, the Cup-moss, which frequents nooks about stone walls and banks. Over its powdered surface are distributed small shallow cups on stalks, *apothecia*. They contain spores. The spore cases rise from the inside of the cup, and the spores are set free when the cup is wetted. If the spores meet with algal forms to which they are partial, they unite with them, and a new lichen thallus is originated (Fig. 117).

The multiplication and dispersal of Lichens is also accomplished by simple vegetative means, in which both the communists share. The thallus breaks up into fragments; every fragment consists of a wrapping of hyphæ round one or more of the algal cells. The bits are blown or washed away and can renew their active life when they find a suitable spot.

The colours of the Lichens are due to acids peculiar to them. Dyes are obtained from them; the litmus of the laboratory is another derivative.

Lichens fill an important rôle in the formation of soil; they may be the originators of it. Their high resistant powers—against drought, starvation, heat, cold—render them better fitted than any other plants to get and keep a footing on bare rock. Every Lichen whilst it lives is creating new organic substance from the air and minerals; when it dies it leaves behind it a few grains of humus. This accumulates as the generations pass and mixes with the debris of the rock; so, a little soil.

It may be just enough to support a hardy little moss plant. Then more plant remains; soon humus and soil pile up more quickly. Then come such higher plants as need no great depth of soil. Finally a full community becomes a possibility.

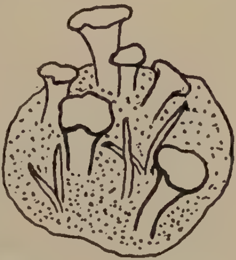

Fig. 117. Lichen: "Cups" of Cladonia

The leaf-like structures are "cups" in the early stage.

It is evident that Lichens do not form a new and independent class of plants. They do not fall naturally into a place in classification lists. Usually, they are grouped with Fungi because the reproductive parts are those used in their classification.

APPENDICES

APPENDIX I

PLANT SENSITIVITY

A BOOK called *Plant Autographs*, by Sir J. C. Bose, of Calcutta, published in 1927, is so full of suggestive theories and ingenious experimental investigations that students should read it if possible. The author attacks some of the most baffling questions in botany, and he works out very startling solutions.

He shows the essential similarity of plant and animal. As the animal responds to external stimuli through the mechanism of its system of nerves and nerve centres, so, he concludes, does the plant. The response of the Sensitive Plant to stimuli is only an obvious and extreme case; every leaf and twig on a tree, in some measure, responds—"even to the passage of a cloud across the sky. . . . The tree as a whole is instinct with sensibility." The stimulus may be heat, light, electric shocks, blows, cuts, etc.; its nature is immaterial; its intensity *does* matter.

Some parts of the plant are more sensitive than others, and upon this depend certain well-known phenomena. For instance, the pulvinus of the Sensitive Plant (p. 207) contains a mass of cells having specialised contents which stain deeply with safranin; they are massed chiefly on the under-surface. *Direct* excitation of a sensitive plant causes loss of turgidity and contraction of the cells. Excitation applied at a distance (*indirect*) causes distension of the tissues. A stimulus may be too feeble to produce this effect; if it is too strong it may induce a reversal of effect. Bose uses these theories to explain phenomena of growth, phototropism and twining organs of plants. A stimulus of a certain strength applied directly to the growing region of a plant checks growth or even induces contraction; if applied at some distance from that region it incites to increase of growth. One-sided illumination acts as a direct stimulus on the near side of the growing region of a shoot, causing contraction and a concave curvature; also as indirect stimulation on the far side, resulting in expansion and convex curvature; the two combine to give the positive phototropic result. Similarly when one side of a tendril comes in contact with a support friction acts as a stimulus to cause contraction in the tendril where the surfaces touch, and hence a grip is taken on the support.

Light and heat operate in the same way in the closing movements of flowers and the "sleep" movements of leaves; the change in intensity of the stimulus promotes or checks growth to a different degree in different parts of the organs; the changes in position follow this. It is a difficult matter to settle whether the deciding factor is light or heat; both are possible.

Bose used electric probes to locate the tissues which function in the plant, as nerves do in the animal. He decided that the inward conducting tract is the external phloem, and the outward (i.e. away from a nerve centre such as a pulvinus) is an internal phloem which he assumes to be universally present. An impulse travels throughout a plant as nerve force travels through an animal's body. This is held to account for the chain of movements in *Mimosa*, in the leaves of Sundew, in the twisting petioles of leaves seeking the sun, etc. But it also covers the multitudes of small unnoticed responses which follow every variation in the conditions to which the plant is exposed.

Bose arrives at a very startling explanation of conduction of water to the tops of trees. It is due, he says, to the action of a pulsating organ which corresponds to the heart of an animal. He identifies it with the cylindrical layer of cortical cells which lies immediately external to the endodermis. The contents of each of these cells pulsates rhythmically, but more forcibly in the lower tracts—so that an upward movement of the whole system is the result. The xylem is a subsidiary water-reservoir.

There is much food for thought and discussion and experimental investigation in this interesting book. It should help the student to cultivate that open and critical mind which alone will lead him on to real search for scientific truth.

APPENDIX II

FAMILY: CARYOPHYLLACEÆ

Leaves. Opposite and entire, exstipulate; rise from swollen nodes.
Inflorescence. Dichasium, with many variations.
Flower. Regular.
Sepals. Four to five.
Petals. Four to five.
Stamens. Twice as many as petals, hypogynous or perigynous.
Carpels. Two to five, syncarpous; styles, two to five; one-celled ovary, numerous ovules, free central placentation.
Fruit. Capsule opening by four to ten teeth.

This Family can be readily subdivided into two groups: (*a*) the Chickweed tribe, the simpler of the two, which has a polysepalous calyx and open flowers; (*b*) the Campion tribe with a gamosepalous calyx.

(*a*) Many of these are plants of the waste; many are tiresome weeds; they may be *ephemerals*, i.e. producing several crops in a season. The Chickweed (*Stellaria media*) is a self-pollinated ephemeral; its only hairs stand in one line down the stem. The Mouse-ear Chickweeds (*Cerastium*) are hairy plants. The Stitchwort (*Stellaria Holostea*) often grows amongst the hedge Grasses; its petals are cut very deeply. Field Spurrey and the Sandworts are weeds of the cornfields. Sandworts, Pearlworts and Chickweeds are often found on stone walls. Sea Purslane, which grows on sandy seashores, has fleshy leaves.

(*b*) These are often perennials. The flowers are generally larger than those in (*a*). They are tubular; the petals often consist of a very narrow base (the *claw*) and a broad upper part (the *limb*), and from the junction between these two a ligule may project so that the corolla-throat is practically closed. The outer whorl of stamens is opposite the petals. The nectar lies at the base of the stamens, and the long narrow corolla-tube restricts it to Moths, Butterflies and long-tongued Bees. Insect-pollination is common.

The White Campion has a marked corona of ligular scales. It is diœcious. It opens at night and is pollinated by Moths. The Bladder Campion is another white Moth flower. Its calyx becomes greatly inflated after fertilisation; the completely chambered ovary of the young flower is changed as it ripens, by the breaking down of the septa and the central column in the upper part of the ovary. The Red Campion is diœcious; it is a "day" flower. The Catchfly bears many sticky hairs in which insects are caught. The Pinks (*Dianthus*) have pale-green wax-coated leaves; they have two styles; they are favoured by Butterflies. Corncockle is a cornfield weed. Carnations and Sweet William are garden representatives.

FAMILY: PRIMULACEÆ

Annual or perennial herbs.
Leaves. Generally simple, alternate, exstipulate, often radical.
Inflorescence. Varied, may be solitary.
Flower. Usually regular.
Sepals. Five, usually gamosepalous.
Petals. Five, gamopetalous.
Stamens. Five, opposite to and seated on petals.
Carpels. Five, syncarpous; ovary superior, one-celled, free central placentation.
Fruit. Capsule, dehisces by five valves.

Many species in this Family are heterostylic, e.g. Primrose, Cowslip, Oxlip, Yellow Loosestrife, etc. Flowers are often protandrous. Self-pollination probably occurs. Two groups may be distinguished: flowers of open form, adapted to short-tongued Flies, and flowers with long corolla-tubes, visited by Bees and Butterflies, e.g. Primrose.

Scarlet Pimpernel is a weed of cultivated land. Its petals bear stalked glands; its flowers are solitary; the corolla has no tube; the capsule opens by the splitting away of a rounded lid. Moneywort has small, round, opposite leaves, trailing stems and solitary flowers. Bird's-eye Primrose (*Primula farinosa*) is whitened with mealy dust; it grows in wet places. The Chickweed Wintergreen of the heaths bears its flower on a very slender stalk. The Water Violet (*Hottonia palustris*) grows in pools and ditches; it has divided submerged leaves; its beautiful purple inflorescences rise just above the water; it hibernates by buds which settle at the bottom of the water. Sea Milkwort (*Glaux*), a plant of the sea-marshes, has fleshy leaves and an apetalous flower. The cultivated Auricula is *Primula Polyanthus*; Cyclamen has reflexed petals.

FAMILY: SCROPHULARACEÆ

Herbs, annual or perennial, stems often square.
Leaves. Exstipulate.
Inflorescence. Racemose or cymose.
Flower. Zygomorphic.
Sepals. Five, gamosepalous.
Petals. Five, gamopetalous, often bilabiate.
Stamens. Four, two long and two short, epipetalous.
Carpels. Two, syncarpous, superior; ovary two-celled; style apical; stigma bilobed. Honey on disk below ovary.
Fruit. Capsule.

Comparison should be made with Labiatæ; the chief difference is in the ovary. Many plants belonging to this Family are poisonous, Figwort is often visited by Wasps which are attracted by its "meaty" odour and colour; the scale on its upper corolla-lip is a *staminode* (arrested stamen). In Ivy-leaved Toadflax, which is common on walls, the fruit-stalks twist so as to embed the fruits in crevices in the wall. Musk (*Mimulus*) grows in or near streams; its stigma is sensitive to touch. The flower of Mullein is nearly regular; its five stamens have very hairy filaments. The flower of Germander Speedwell is almost regular. Its two stamens are grasped by the Drone Flies which often visit it and the pollen is brought into contact with the Fly's body—at the same time the under side of the Fly may be depositing on the centrally placed stigma pollen brought from another flower.

The parasite Toothwort belongs to this Family, and also the semi-parasites Bartsia, Eyebright, Cow Wheat, Yellow Rattle, Lousewort. Other examples of plants belonging to this Family are Foxglove, Bastard Toadflax, Snapdragon, Calceolaria, Pentstemon.

FAMILY: LABIATÆ (LAMIACEÆ)

Herbs or small shrubs, with square stem.

Leaves. Simple, opposite and decussate, exstipulate, often hairy or with oil glands.

Inflorescence. Racemose, passing over to cymose in smaller branches; cymes may look like a whorl.

Flower. Zygomorphic, hypogynous.

Sepals. Five, gamosepalous, bilabiate or tubular; calyx persistent.

Petals. Five, gamopetalous, bilabiate.

Stamens. Four, didynamous, epipetalous (fifth, posterior is suppressed).

Carpels. Two, syncarpous; style, gynobasic; stigma, bifid; ovary superior, four-celled with false septum.

Fruit. Four nutlets.

The Family contains many aromatic herbs—Rosemary, Lavender, Thyme, Mint, Marjoram, Garden Sage, Balm, Sweet Basil. Many, even in England, retain the characters which fitted them for the xerophytic Mediterranean type of climate, e.g. hairs, small, hard, evergreen leaves. Many display interesting adaptations to insects, mostly for Bees but also for Moths and Butterflies. Small flowers are visited often by smaller insects. The honey disk is at the base of the ovary.

Amongst the weeds of the cornfield are Hemp Nettle and Corn Mint; in wet places grow Water Mint, Greater Skullcap and Gipsywort. Ground Ivy forms a ground carpet of soft leaves; its flowers may be pistillate only. Bugle has blue flowers with a very short upper lip beyond which stamens and style protrude; Wood Sage has the same form of lip. The pollinating mechanism of Garden Sage should be studied. Wild Thyme is a small prostrate plant; it has many spikes of flowers, three in each; the corolla is almost regular. Rosemary has specially narrow under-rolled leaves.

FAMILY: SALICACEÆ

Trees or shrubs.
Leaves. Simple, alternate, stipulate.
Inflorescence. Catkin, unisexual, diœcious.

A. *Salix* (willow). *Male flower* in axil of bract. No perianth. Two to five *stamens*. *Female flower* has two *carpels*, syncarpous. Stigma two-lobed. Unilocular ovary with numerous ovules. *Fruit* a capsule. Seeds with ring of hairs arising from base. Both forms of flower have nectaries consisting of one or two scales. Pollination is by insects (Fig. 118).

B. *Populus* (Poplar). *Male flower*, rudimentary perianth. Many stamens standing in a cup-like disk. There are no nectaries. *Female flower*, ovary within a disk also. No nectaries. Pollination by wind.

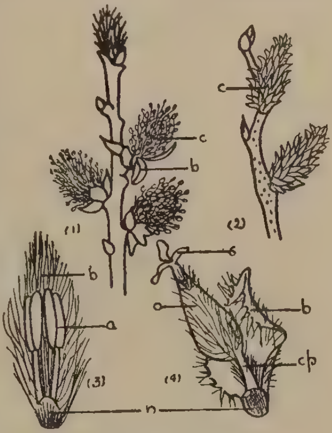

FIG. 118. WILLOW FLOWERS

(1) Male inflorescence; (2) Female inflorescence; (3) Single male floret; (4) Single female floret.

c, catkin; *b*, bract; *a*, anther; *n*, nectary; *s*, stigma; *o*, ovary; *cp*, carpophore (prolongation of axis).

CHARACTERS OF INSECT-POLLINATED FLOWERS

(1) Attractions of form and colour, both in flower and in inflorescence.
(2) Food in the form of nectar and pollen.
(3) Adaptations to particular types of insect.
(4) Alighting platforms—flower and inflorescence.
(5) Scents favoured by particular insects.
(6) A moderate amount of pollen.
(7) Pollen is rough or sticky.
(8) Stigma more compact and less out-thrust than in anemophilous flowers.

CHARACTERS OF WIND-POLLINATED FLOWERS

(1) They are often flowers of trees and shrubs, and of the grasses, etc., of windswept places. Often they flower before the leaves are spread.

(2) Flowers inconspicuous, often reduced.
(3) Many stamens, freely exposed, dehisce in dry weather.
(4) Pollen in great quantities, dry, smooth, powdery.
(5) Stigma feathery, branched, projecting.
(6) Absence of nectar and odour.

POLLINATING AGENTS

(1) Insects . .	Entomophilous flowers	Cross-pollination.
(2) Wind . .	Anemophilous flowers	
(3) Water . .	In aquatics	

(4) Special disposition and movements of floral members resulting in self-pollination.

FAVOURING CROSS-POLLINATION

(1) Unisexual flowers: self-pollination impossible. (*a*) Two sexes on one plant—*monœcious*; (*b*) on different plants—*diœcious*.

(2) Male and female organs do not ripen at the same time—conditions of *dichogamy*. (*a*) Anthers ripening first—*protandry*; (*b*) stigma ripening first—*protogyny*.

(3) All the advantages offered to insect visitors.

(4) Adaptations to wind-pollination.

(5) Extrorse dehiscence of stamens.

(6) Anthers standing at lower level than stigma in upright flowers.

(7) Some flowers self-sterile, i.e. cannot be fertilised by their own pollen.

FAVOURING SELF-POLLINATION

(1) It is possible only in hermaphrodite flowers.

(2) Anthers and stigmas mature at the same time.

(3) Relative positions of floral whorls such that pollen is likely to reach stigmas on the same flower.

(4) Closure movements of flowers which carry pollen to stigma.

(5) Flowers which never open (p. 180).

(6) Self-pollination sometimes provided for after cross-pollination has had a chance, e.g. the curling back of the stigmas in some Composites.

PARTS OF PLANTS IN COMMON USE

Satisfy yourself by examining specimens, in various stages if necessary, that the following statements are correct.

The edible *Chestnut* is a true nut. When it leaves the tree, the brown shiny nut is enclosed in a spiny capsule formed from the bracts which surrounded the female flower.

The *Coco-nut* is a drupe. Only part of the fruit usually appears in the shops. Complete, its coverings consist of a hard, rather smooth, surface coat, a middle padded jacket of coarse fibres, and an internal, very hard shell—all three are modified parts of the pericarp. The three dark, circular depressions at one end of the shell indicate that the ovary had been three-chambered. Only one depression is easy to pierce; through that would have come out the radicle of the solitary seed (one out of three) which develops. The white "meat" of the Coco-nut and the "milk" are two forms of endosperm. The whole fruit is waterproof, and buoyant in water.

The *Date* is a one-seeded berry. The pulpy part is pericarp. The "stone" is the seed; most of its bulk consists of endosperm, and the food substance in this is the thick cellulose walls. The tissue-paper-like covering of the "stone" is the testa. The embryo, about the size of a pin-head, lies near one end, on the side opposite the furrow. You might plant a "stone" and watch how the embryo feeds itself from its stony stores.

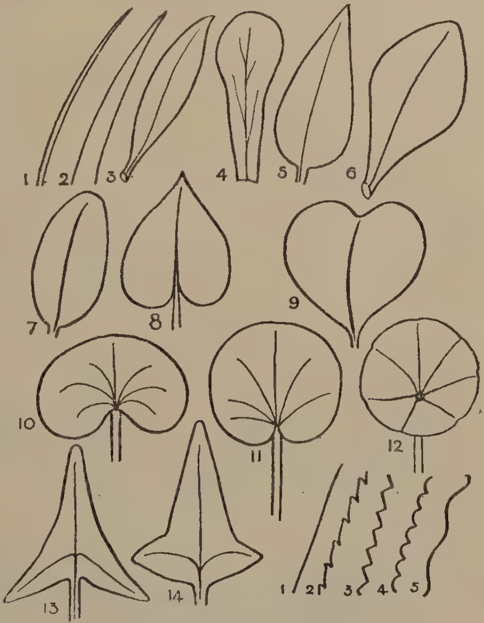

Fig. 119. Forms of Leaves

(1) Acicular; (2) Linear; (3) Lanceolate; (4) Spatulate; (5) Ovate; (6) Obovate; (7) Oval; (8) Cordate; (9) Obcordate; (10) Reniform; (11) Orbicular; (12) Peltate; (13) Sagittate; (14) Hastate.

Leaf-margins: 1, entire; 2, serrate; 3, dentate; 4, crenate; 5, sinuate.

The *Orange* is a berry. The "quarters" can be traced to the carpels, and the juicy morsels are plump hairs which have grown out from the carpels.

The *Pear* is a disguised fruit. The ovaries proper became the core, within whose cavities lie the seeds. As the flower gave place to the fruit, the receptacle grew bulkier, not only enclosing the ovaries but fusing with their walls.

The *Tomato* is a berry, the product of a superior, syncarpous flower.

The *Walnut* is a drupe. The green Walnut as obtained for pickling shows the fleshy outer portion of the pericarp. The shell is the endocarp; its membranous ingrowths are connected with a fibrous strand at one end which conducts moisture inwards like a bit of cotton. The embryo is a small body lying at the end opposite the strand. The much-crumpled edible matter is formed of the two cotyledons.

The *Beetroot* plant has greatly enlarged roots in which cane sugar is stored. The increase in thickness of the root is due to the activity of extra cambiums which make their appearance and give rise to much parenchymatous tissue: hence there are distinct concentric zones seen in cross-sections.

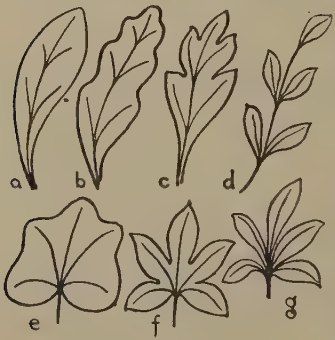

FIG. 120. LEAF-FORM

a–d, series from simple to compound pinnate; *e–g*, from simple to compound palmate.

Brussels Sprouts are buds. The undeveloped axis bears many leaves which hold tiny buds in their axils.

A *Cabbage* is a great terminal bud. Its central leaves are etiolated.

A *Carrot* is a swollen tap-root, containing grape sugar. Its secondary growth of excessive parenchyma is the work of one cambial layer.

A *Cauliflower* is an inflorescence. It was in the first instance one of the abnormal or "monstrous" appearances occasionally found in nature, in which the branches of the inflorescence took a flattened form and coalesced extensively among themselves. Cultivation has fixed this form.

Celery. The part eaten is the leaf-stalk, much drawn out and bleached by being deprived of light.

The *Radish* consists of root in the lower part, hypocotyl in the upper.

The *Turnip* is like the Radish in the points mentioned.

Cork. A bottle cork is a slab cut from the thick bark of the Cork Oak. The brown slits are lenticels, and if the cork is to be efficient they must run across the cork.

Cotton. The fibres which are used in spinning are the long hairs which grew on the seeds of the Cotton plant.

Flax. The strong bast fibres of this plant are used for making linen thread.

EXERCISES IN DESCRIPTION

The list of specimens given below is intended to afford practice in the selection of features for description. Do not write full descriptions, make brief notes; illustrate the points you select by sketches. In every case there is present one special character which has led to the inclusion of the specimen in this list. Make sure of this and give it prominence in your notes and drawings.

List of Specimens

Anemone, flower; Artichoke, tuber; Asparagus, foliage; Bittersweet, branching stem; Butcher's Broom, branch; Castor Oil, seed; Christmas Rose, flower; Cotton Grass, fruit; Daisy, whole plant; False Oat, underground parts; Garden Geranium, inflorescence; Gooseberry, spray, flower and fruit; Guelder Rose, inflorescence and leaves; Harebell, whole plant; Hawthorn, branch which has not been pruned; Hawthorn, fruit; Holly, fruit; Honesty, fruit; Hop, fruit; Houseleek, whole plant; Ivy, fruit; Lime, fruit; Ling, leaves; Love-in-a-mist, flower; Marsh Marigold, tissues of petioles, etc.; Mat Grass, leaves; Meadow Pea, stem and leaves; Medick, fruit; Mustard and Cress, seedlings; Rhododendron, leaves from city park; Stonecrop, whole plant; Thistle, fruit; Violet, fruit; Water Lily, petiole and seeds; Winter Aconite, flower; Winter Cherry, fruit.

CHEMICAL TESTS

Nitrates. Dry the soil to be tested. Arrange it so as to obtain a filtrate by the slow passage of water through it. To some of the filtrate in a test-tube add ferrous sulphate solution. Pour a few drops of strong sulphuric acid carefully down the side of the test-tube. A brown ring forming between the two solutions indicates the presence of nitrate. The ring disappears if the test-tube is shaken.

Protein. (*a*) Add strong nitric acid to the substance to be tested and boil in a test-tube; the solution turns yellow. Allow it to cool and add strong ammonia; the solution turns orange.

Or (*b*) Take equal quantities of material to be tested and strong caustic soda solution; add a few drops of copper sulphate solution. Peptone gives a pink coloration, protein gives purple.

Fehling's test for grape sugar. Fehling's solution:

(1) Dissolve 35 grm. copper sulphate in 200 c.c. water.
(2) Dissolve 70 grm. Rochelle salt in 200 c.c. of ten per cent solution caustic soda.

Add solution (1), and then solution (2), until deep-blue solution is obtained. On heating, a deep orange precipitate is formed with grape sugar.

Cane Sugar. Boil the substance to be tested with dilute sulphuric or hydrochloric acid. This changes cane sugar into grape sugar. The presence of the latter would be shown by Fehling's test.

Cellulose. The cell walls of an herbaceous plant or the mass of the Date seed may be tested for this. Cellulose is stained blue by the iodine test after it has been treated with sulphuric acid.

Inulin. This is soluble in water but not in alcohol; it exists in solution in cell sap. Place sections cut from plants of the Compositæ Family in methylated spirit, and leave them for about a fortnight. Examine thin sections under the microscope; inulin, if present, will have crystallised out as sphæro-crystals—semicircular on the walls of the cells, or spherical masses of crystals in the centre. These crystals can be re-dissolved in water.

Fixed Oils. Test nuts, olive seeds, etc., for these. Rubbed on paper, oily tissue leaves a stain which can be removed by ether or methylated spirit; oil is soluble in these. If treated with osmic acid, oils give a very dark brown stain.

GREEK ROOTS AND DERIVATIVES

NOTE.—English "y" used as equivalent of Greek "υ."

ROOT.	MEANING OF ROOT.	DERIVATIVE.
a	not	akene
adelphos	brother	monadelphous
aggos	a vessel	angiosperm
aktis	a ray	actinomorphic
aner andros (*Genit.*)	a male	andrecium
anemos	wind	anemophilous
anthos	a flower	perianth
apo	apart	apocarpous
autos	self	autogamy
bios	life	biology
chaino	I gape	akene
chloros	green	chlorophyll
derma	skin	epidermis
di	double	dicotyledon
dicha	apart	dichogamy
edaphos	the ground	edaphic
endon	within	endosperm
entomos	an insect	entomophilous
epi	upon	epicotyl
gamos	union	gamosepalous
ge	the earth	epigeal
geiton	a neighbour	geitonogamy
gymnos	naked	gymnosperm
gyne	female	hypogynous
hals	salt	halophyte
helios	the sun	heliotropism
heteros	different	heteromorphic
hodos	a way	hydathode
hydor	water	hydrotropism
hygros	moist	hygrophyte
hypo	under	hypogynous

ROOT.	MEANING OF ROOT.	DERIVATIVE.
kalyx	a cup	calyx
karpos	a fruit	apocarpous
kleistos	closed	cleistogamous
leukos	white	leucoplast
meros	a part	merocarp
mesos	middle	mesophyte
micros	small	micropyle
monos	one	monœcious
morphe	shape	actinomorphic
mykes	fungus	mycorhiza
oikos	a house	ecology
peri	round	pericarp
philos	loving	anemophilous
phos	light	photosynthesis
phyllon	a leaf	phyllotaxis
phyton	a plant	halophyte
poly	many	polypetalous
proteros	before	proterogynous
pyle	a gate	micropyle
rhiza	a root	rhizome
sapros	rotten	saprophyte
schizo	I split	schizocarp
sperma	a seed	endosperm
stoma	a mouth	stoma (*pl.* stomata
syn	together	syncarpous
synthesis	a placing together	photosynthesis
tropos	turning	geotropism
xeros	dry	xerophyte
zygos	a yoke	zygomorphic

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